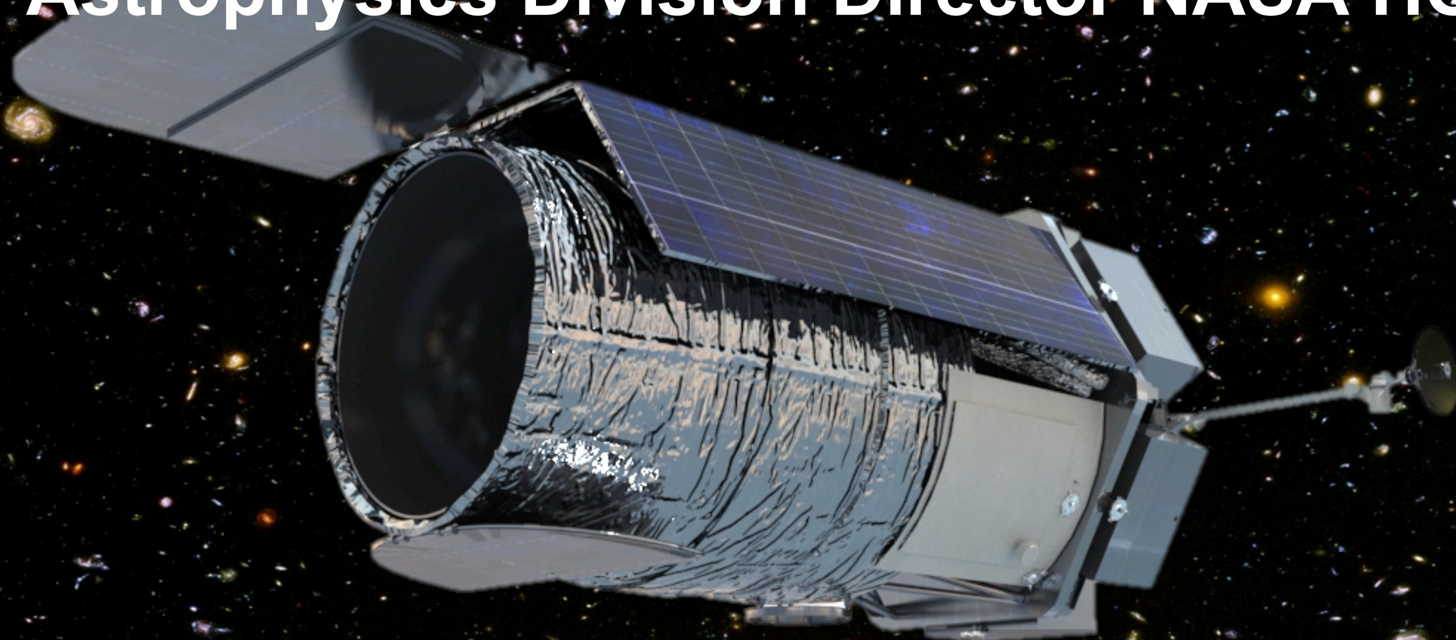
WFIRST-AFTA Science Definition Team Final Report Presentation to Paul Hertz, Astrophysics Division Director NASA HQ



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February 13, 2015

WFIRST-AFTA SDT

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- Yannick Mellier, European Space Agency
- Wes Traub, NASA JPL
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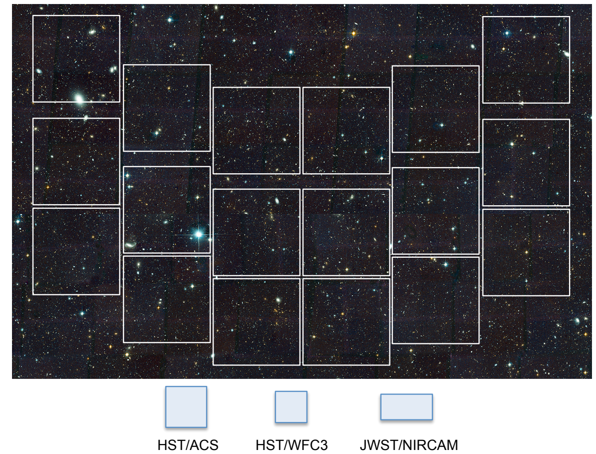
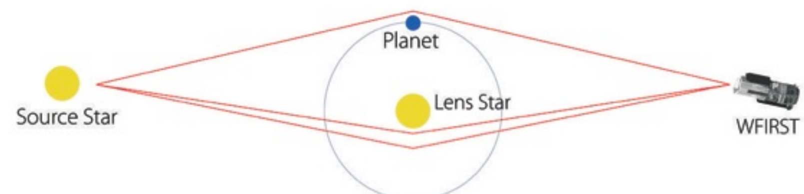
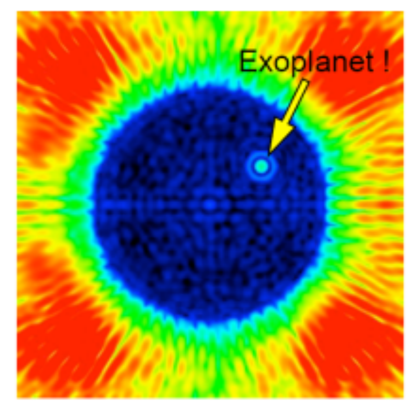
WFIRST-AFTA Summary

- WFIRST is the highest ranked NWNH large space mission.
  - Determine the nature of the dark energy that is driving the current accelerating expansion of the universe
  - Perform statistical census of planetary systems through microlensing survey
  - Survey the NIR sky
  - Provide the community with a wide field telescope for pointed wide observations
- Coronagraph characterizes planets and disks, broadens science program and brings humanity closer to imaging Earths.
- WFIRST gives Hubble-quality and depth imaging over thousands of square degrees
- The WFIRST-AFTA Design Reference Mission has
  - 2.4 m telescope (already exists)
  - NIR instrument with 18 H4RG detectors
  - Baseline exoplanet coronagraph
  - 6 year lifetime







Executive Summary

- “HST quality” NIR imaging over 1000's of square degrees.
- 2.5x deeper and 1.6x better resolution than NWNH requirements
- More complementary to Euclid & LSST. More synergistic with JWST.
- Enables coronagraphy of giant planets and debris disks to address "new worlds" science and technology development in NWNH.
- Fine angular resolution and high sensitivity open new discovery areas to the community. More GO science time (25%) than for IDRM.
- WFIRST-AFTA addresses changes in landscape since NWNH: Euclid selection & Kepler discovery that 1-4 Earth radii planets are common.
- Use of existing 2.4-m telescope and addition of coronagraph have increased the interest in WFIRST in government, scientific community and the public. Funding interest in Congress and STMD have advanced the mission.
- WFIRST-AFTA design has significantly matured over the past two years.

WFIRST-AFTA Status

- Significant WFIRST-AFTA funding added to the NASA budget by Congress for FY14 and FY15 for a total of $106.5M.
- Funding is being used for pre-Phase A work to prepare for a rapid start and allow a shortened development time
  - Detector array development with H4RGs
  - Coronagraph technology development
  - Science simulations and modeling
  - Observatory design work
- ROSES "Preparatory Science Opportunity" proposals selected. Seventeen proposals funded at ~$150k each.
- NASA HQ charge for telescope is "use as is as much as possible" and for coronagraph is "not drive requirements". Study Office / SDT driving toward the fastest, cheapest implementation of the mission
- Community engagement: PAGs, conferences and outreach
  - Special sessions held at January & June 2014 and January 2015 AAS conferences
  - Wide-Field Infrared Surveys conference held in November 17-22, 2014 in Pasadena

NRC Review

- Performed in January-February 2014 to determine if WFIRST-AFTA meets the WFIRST requirement in NWNH
- NRC endorsed the strength of the WFIRST-AFTA science
  - “The observing program envisioned for WFIRST/AFTA is consistent with the science program described for WFIRST in NWNH.”
  - “The importance of exploring the diversity of planetary systems in the parameter space probed by the WFIRST microlensing survey is vital as it was in NWNH. No other current mission or technique can address this issue. Both WFIRST/IDRM and WFIRST/AFTA can carry out the envisioned survey.”
  - “The WFIRST/AFTA coronagraph satisfies some aspects of the broader exoplanet technology program recommended by NWNH by developing and demonstrating advanced coronagraph starlight suppression techniques in space.”
  - “NASA should move aggressively to mature the coronagraph design and develop a credible cost, schedule, performance, and observing program so that its impact on the WFIRST mission can be determined.”
- NRC had concerns about the risk introduced by the coronagraph and larger telescope (see next slide) and the Study Office and SDT have worked for the past year to address the concerns.

Risk Areas Identified in the 2014 NRC Report

Concern	Current Status
Low mass margin	Mitigated by new baseline heavy lift vehicle.
Testing of larger payload with 2.4-m telescope	Detailed I&T planning during 2014 to identify tests and workflow for telescope, instruments, and integrated payload.
NIR detector maturity	Detector technology maturation plan underway; milestones being met on schedule.
Launch loads for inherited hardware	Mechanical redesign of the payload, with instrument carrier now supporting the telescope. Launch loads now compatible with inherited hardware with margin.
Telescope temperature and thermal margins	Performance re-assessed, including increased margins and allocations for sub-dominant paths. Current baseline (282 K) within qualified range; minor 0.28 mag loss of depth in HLS F184, less impact in other programs.
Coronagraph maturity	On track to mature coronagraph technology to TRL5 by start of Phase A; milestones being met on schedule.
Coronagraph impact on observatory	Initial simulations of coronagraph performance in WFIRST-AFTA environment indicate that the coronagraph is likely to achieve all performance goals with the current, unmodified telescope.

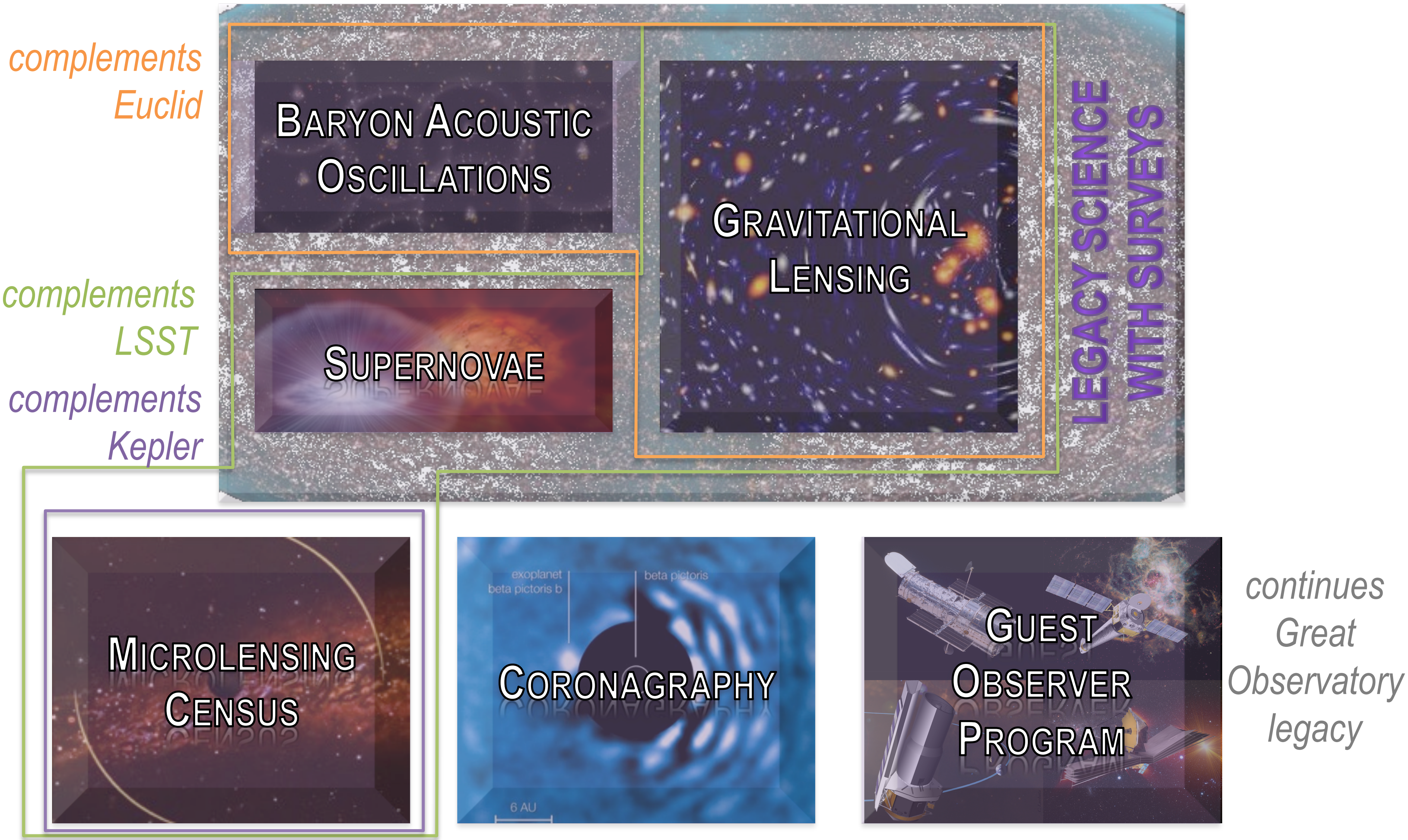
Changes Since 2013 Report Technology/Design

- Development of an integrated modeling effort from telescope thermal environment to final post-processing for both wide field and coronagraph.
- Telescope temperature is now set at 282K. This is within the qualification limits of the original program.
- Completed the first 2 NIR detector technology milestones. Flight recipe selected and full array lot in production.
- Coronagraph is now part of the baseline as a Technology Demonstration instrument.
  - Downselect of coronagraph architectures to a flexible baseline with a high-performance backup
- Demonstration of laboratory performance of coronagraph contrasts with the WFIRST-AFTA pupil
  - Completed the first 3 coronagraph technology milestones and an early demo of milestone 5; milestone 4 due this month.
- Baseline launch vehicle is now a heavy lift vehicle.

Changes Since 2013 Report Science

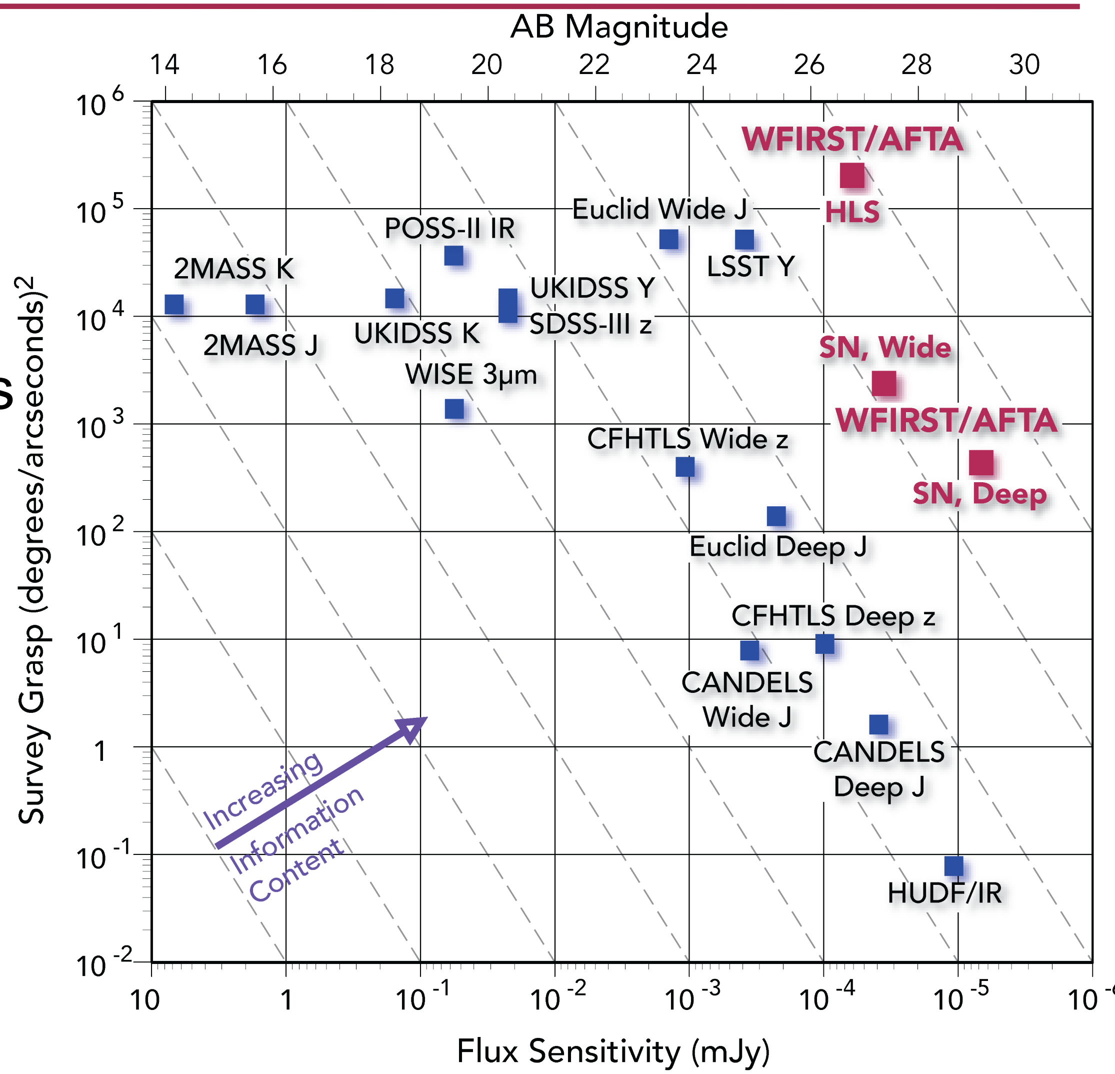
- Planet imaging and spectroscopy yield estimates produced from high fidelity coronagraph performance models
- Simulated circumstellar disk images were produced and used to evaluate sensitivity to detecting exozodiacal disks
- Detailed investigations of supernova observing strategy and its performance; detailed investigations of expected photometric redshift performance and calibration strategies.
- Updated HLS forecasts based on improved understanding of telescope and instrument performance and improved astrophysical inputs.
- Initial look at the science that may be possible from the microlensing galactic bulge survey, including auxiliary science from the microlensing events themselves, stellar astrophysics, Galactic structure, and solar system science.
- Appendix J, written by the community, outlines scientific synergies between WFIRST and future instruments and telescopes. Science cases include opportunities with TMT, GMT, Subaru PFS, LSST, and Euclid.

WFIRST-AFTA Science



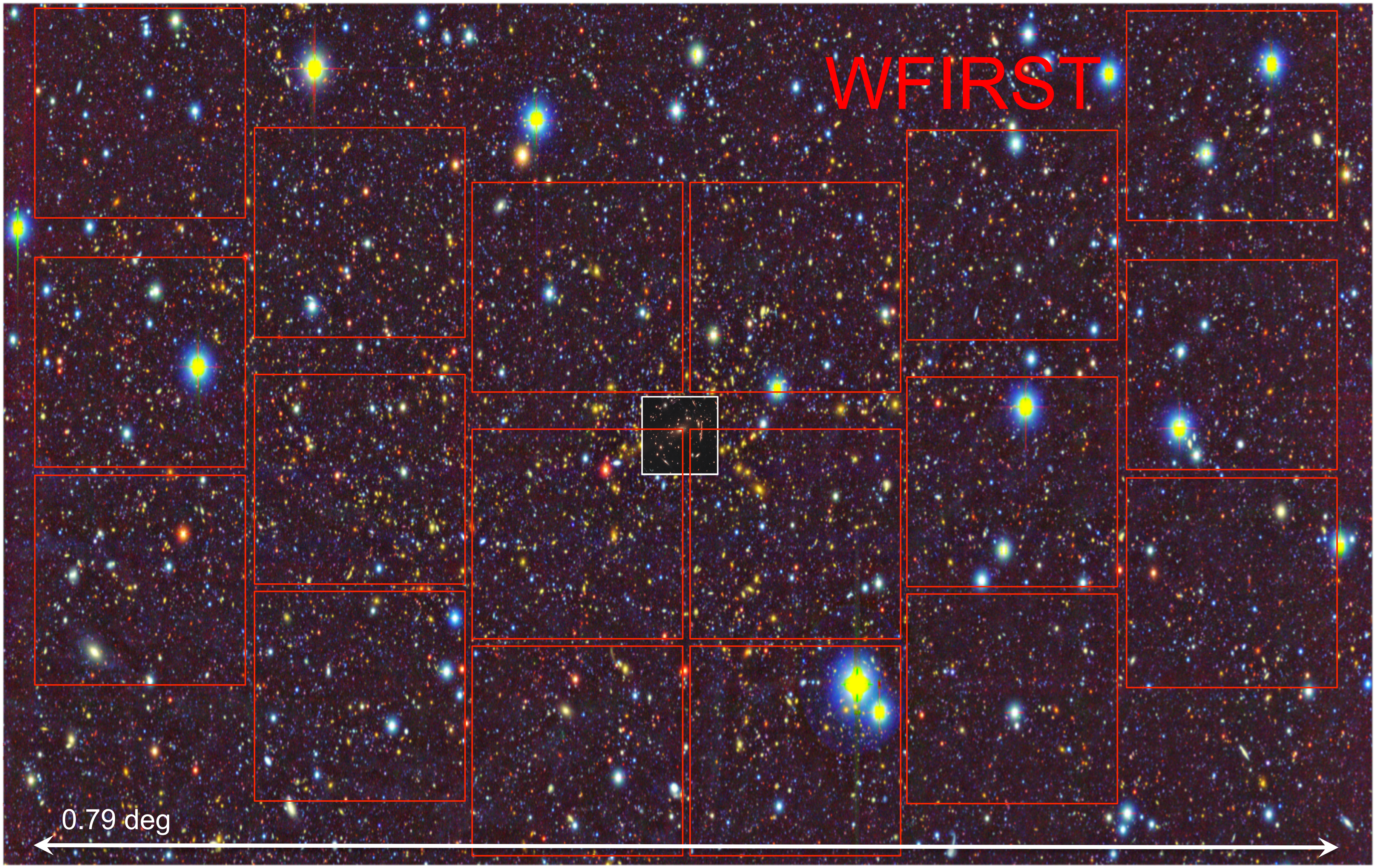
WFIRST-AFTA Surveys

- Multiple surveys:
  - High-Latitude Survey
    - Imaging, spectroscopy, supernova monitoring
  - Repeated Observations of Bulge Fields for microlensing
  - 25% Guest Observer Program
  - Coronagraph Observations
- Flexibility to choose optimal approach

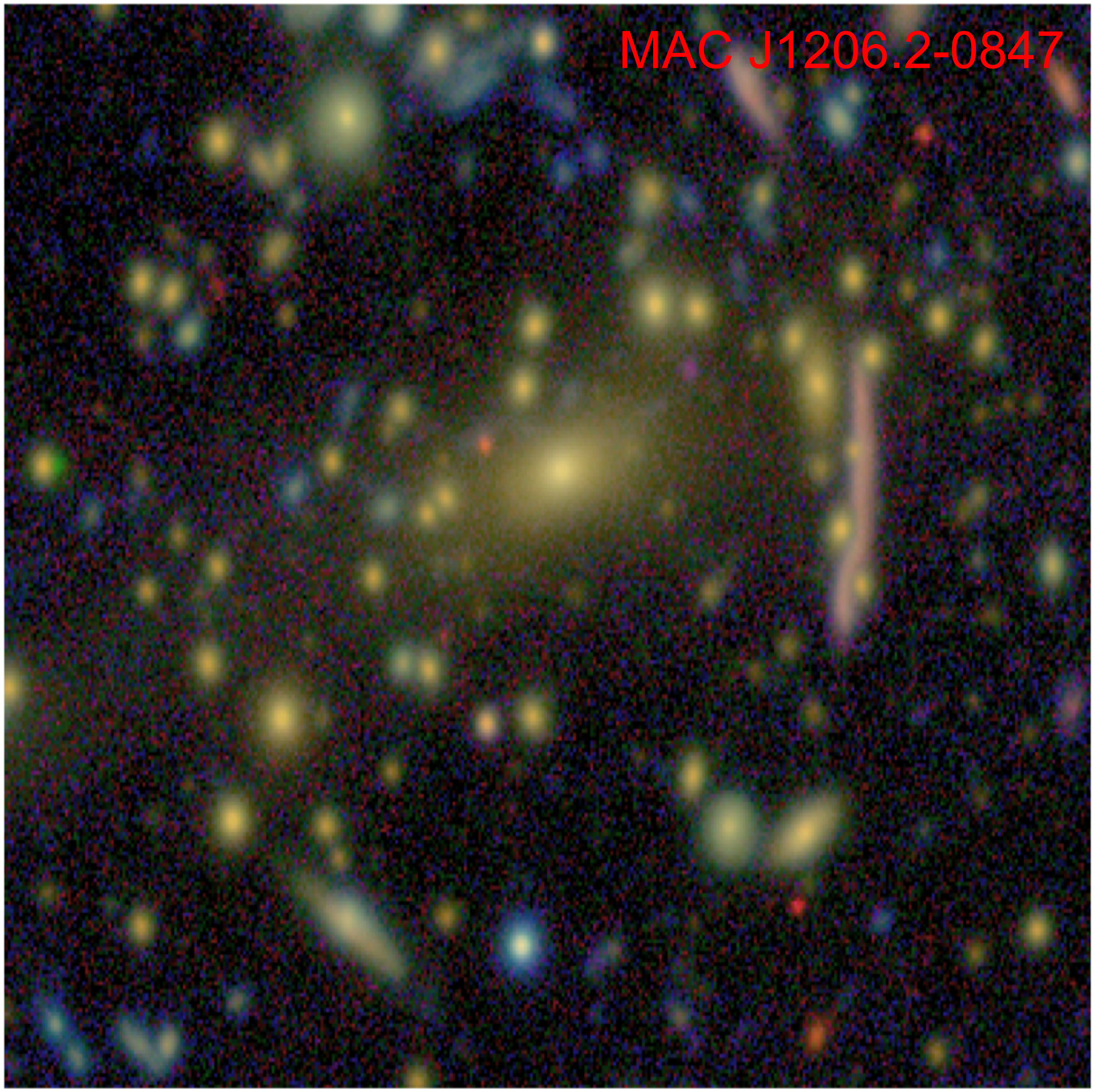


Near Infrared Surveys

Gravitational Lensing



Gravitational Lensing

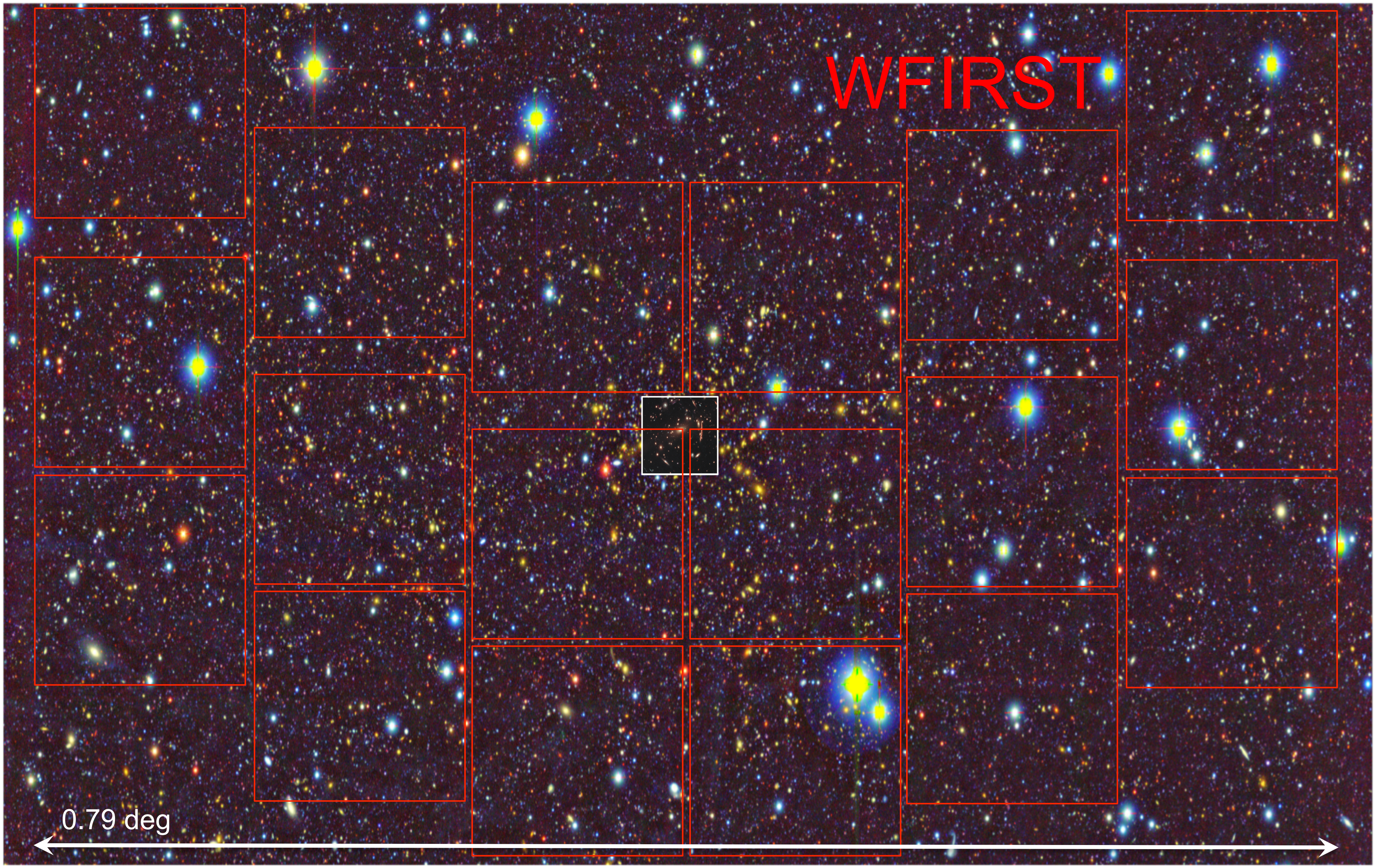


Postman
HST

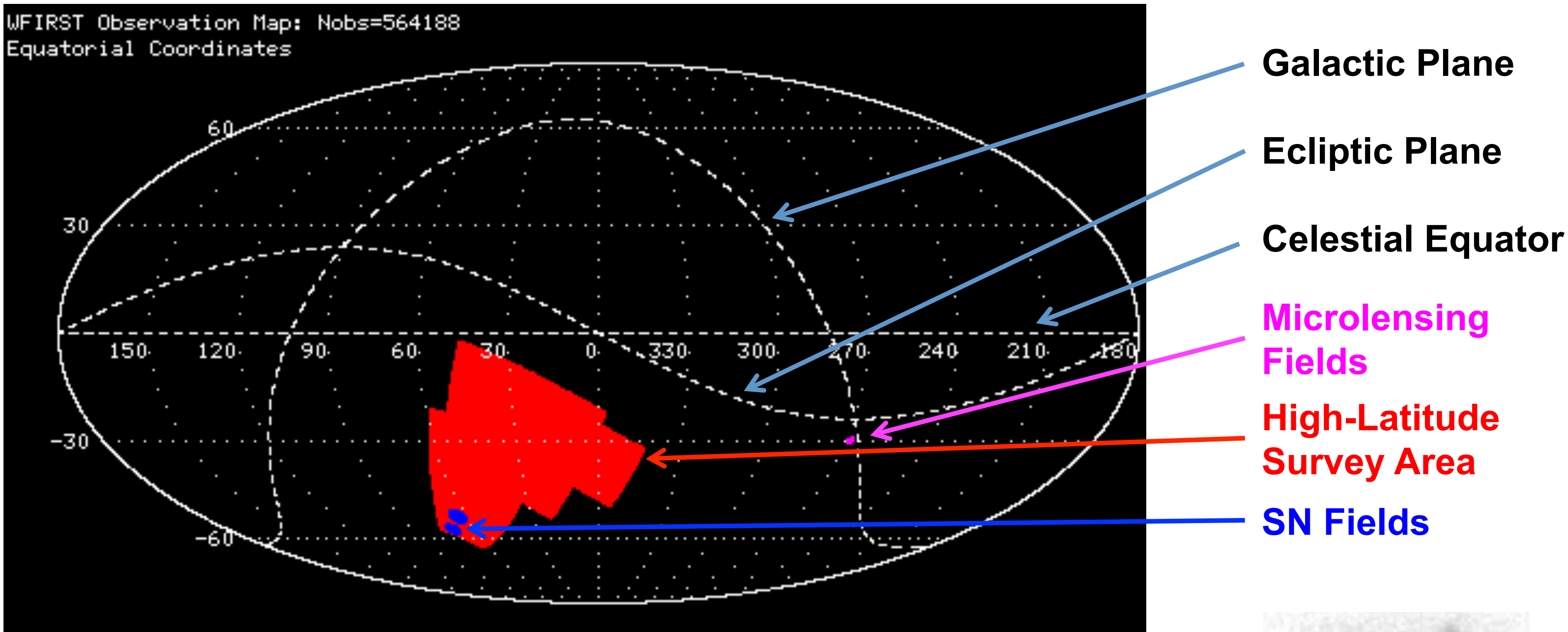
Gravitational Lensing

Postman
HST

Gravitational Lensing

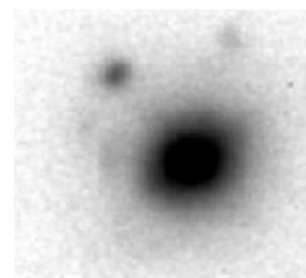


Huge Dynamic Range



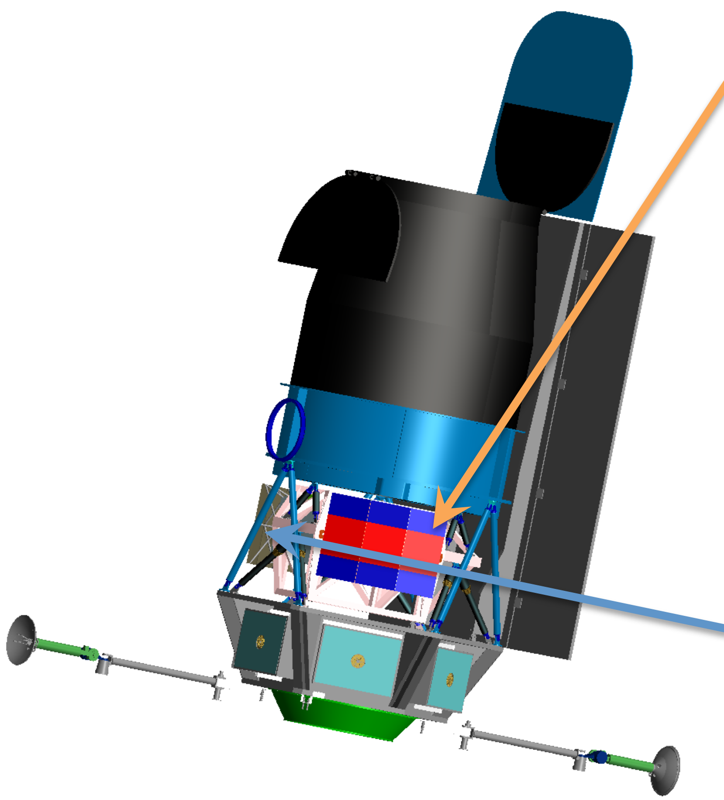
100 deg

~10^6 dynamic range in size
~2×10^{12} resolution elements in HLS



0.1 arcsec

WFIRST-AFTA Instruments



Wide-Field Instrument

- *Imaging & spectroscopy over 1000s of sq. deg.*
- *Monitoring of SN and microlensing fields*
- 0.7 – 2.0 μm (imaging) & 1.35-1.89 μm (spec.)
- 0.28 deg^2 FoV (100x JWST FoV)
- 18 H4RG detectors (288 Mpixels)
- 6 filter imaging, grism + IFU spectroscopy

Coronagraph

- *Image and spectra of exoplanets from super-Earths to giants*
- *Images of debris disks*
- 430 – 970 nm (imaging) & 600 – 970 nm (spec.)
- Final contrast of 10^{-9} or better
- Exoplanet images from 0.1 to 1.0 arcsec

WFIRST Provides Early Coronagraphic Opportunity

- Coronagraph takes full advantage of WFIRST-AFTA 2.4-m telescope to enable revolutionary exoplanet science.
- Highly-leveraged science for a fraction of a full mission cost.
- Coronagraph science fits in WFIRST tripod: dark energy, exoplanets, community surveys
- Addresses NWNH recommendation for investment in direct imaging technology
- Coronagraph addresses NWNH science questions through detection and characterization of exoplanets unreachable from the ground.

Coronagraph Animation

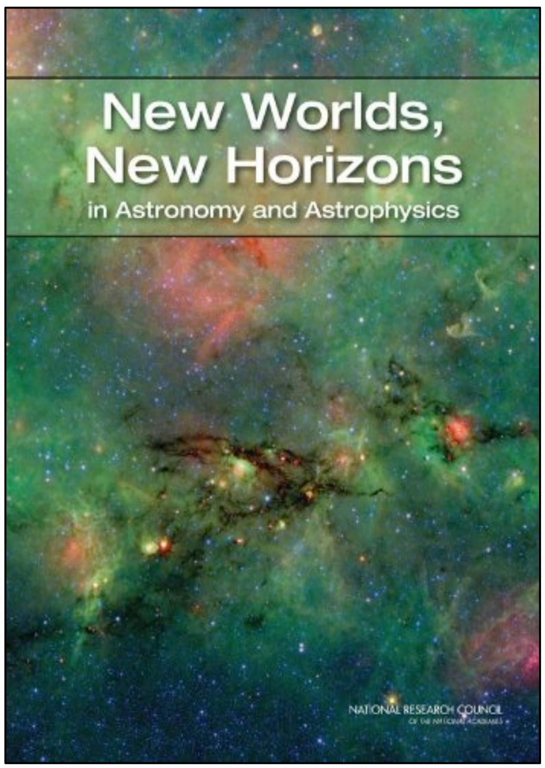
file://localhost/Users/mmelton/Documents/WFIRST/AFTA/SDT/2015 HQ Prsentation/Videos/CoronagraphVideoOneMinute WMV.wmv

25% of WFIRST is GO Time

Frequently discussed

#1 Large-Scale Priority - Dark Energy, Exoplanets
#1 Medium-Scale Priority - New Worlds Tech. Development
(prepare for 2020s planet imaging mission)

WFIRST covers many other NWNH science goals



5 Discovery Science Areas

ID & Characterize Nearby Habitable Exoplanets ✔
Time-Domain Astronomy ✔
Astrometry ✔
Epoch of Reionization ✔
Gravitational Wave Astrometry

20 Key Science Questions

Origins **(7/7 key areas)**
Understanding the Cosmic Order **(6/10 key areas)**
Frontiers of Knowledge **(3/4 key areas)**

Community Members that Submitted 1-page Descriptions of Potential GO Science Programs in the 2013 SDT Report

Capabilities

WFI:

Imager	**0.76-2.0 microns** 0.28˚ FoV, 0.11" pixel scale
Filters:	z (0.76 - 0.98), Y (0.93-1.19), J (1.13-1.45), H(1.38-1.77),
	F184 (1.68-2.0), W149 (0.93-2.00)
Grism:	**1.35-1.89 microns** 0.28˚ FoV, R=461λ, 0.11" pixel scale
IFU:	**0.6-2.0 microns** 3" & 6" FoV, R~100, 0.075" pixel scale

Coronagraph:

Imager:	**0.43-0.97 microns** 1.63" FoV (radius), 0.01" pixel scale, 1k x 1k EMCCD, 10^{-9} final contrast, 100-200 mas inner working angle
IFS:	**0.60-0.97 microns** 0.82" FoV (radius), R~70

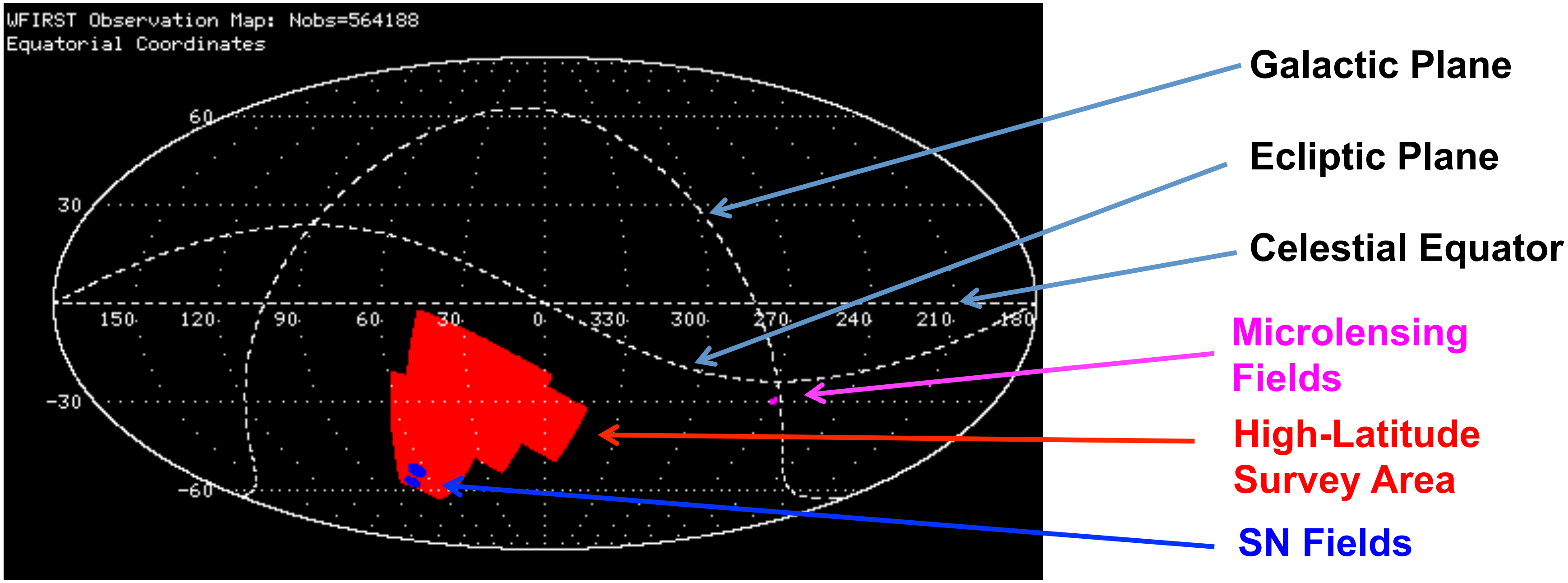
Field of Regard: 54˚ - 126˚ 60% of sky

DRM Yields

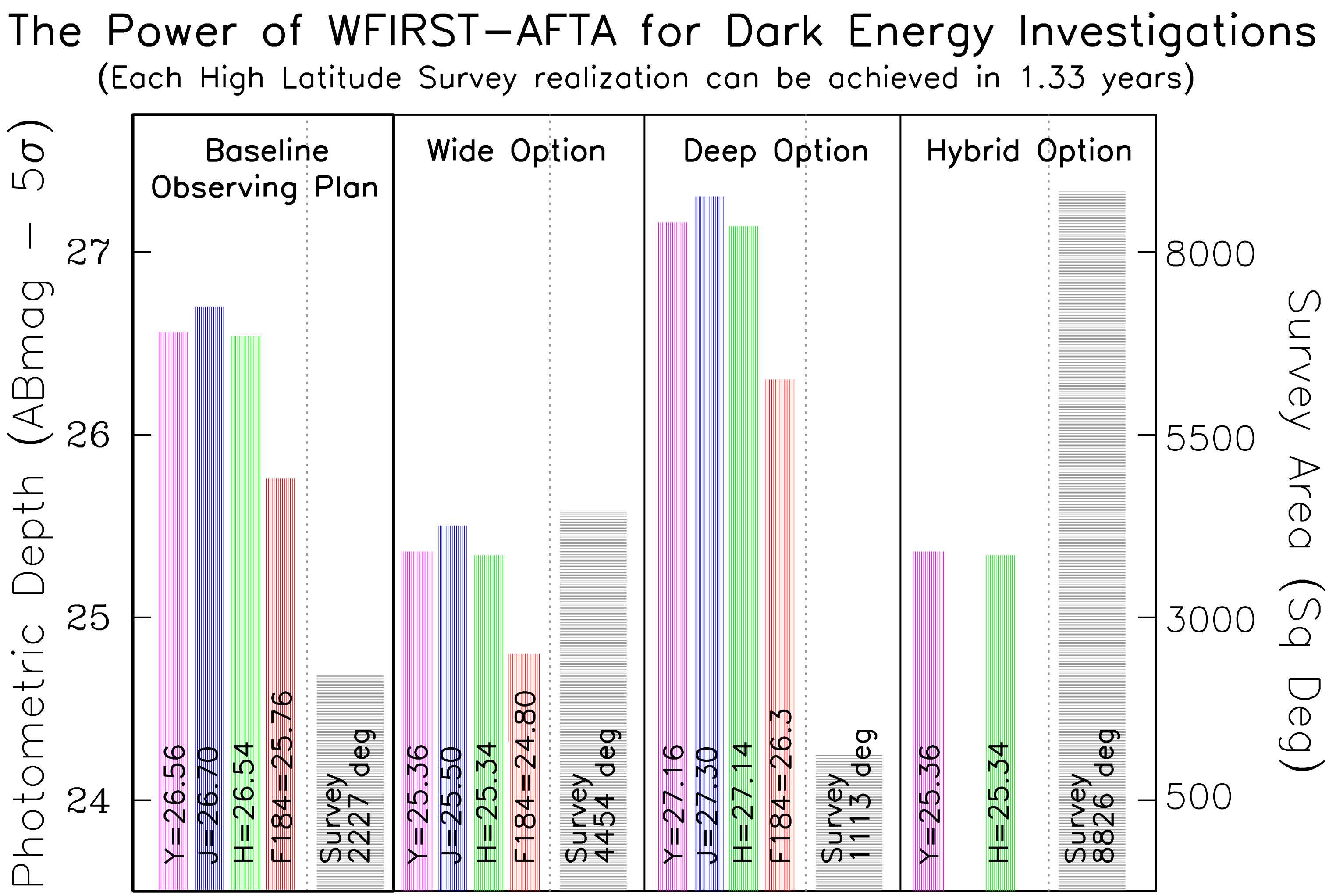
Attributes	WFIRST-AFTA Yields
Imaging survey	J ~ 27 AB over 2200 sq deg
	J ~ 29 AB over 3 sq deg deep fields
Slitless spectroscopy	R~461λ over 2200 sq deg
Number of SN Ia SNe	2700 to z~1.7
Number galaxies with spectra	2×10^7
Number galaxies with shapes	4×10^8
Number of galaxies detected	few x 10^9
Number of massive clusters	4×10^4
Number of microlens exoplanets	2600
Number of imaged exoplanets	10s

Example Observing Schedule

- High-latitude survey (HLS: imaging + spectroscopy): 2.01 years
  - 2227 deg^2 @ ≥3 exposures in all filters (2279 deg^2 bounding box)
- 6 microlensing seasons (0.98 years, after lunar cutouts)
- SN survey in 0.63 years, field embedded in HLS footprint
- 1 year for the coronagraph, interspersed throughout the mission
- Unallocated time is 1.33 years (includes GO program)



Multiple Ways to Balance Survey Depth and Area



Baseline observing plan maximizes number of weak lensing galaxies and redshifts for a 4–band imaging + grism survey in a fixed amount of observing time.

WFIRST-AFTA Dark Energy Roadmap

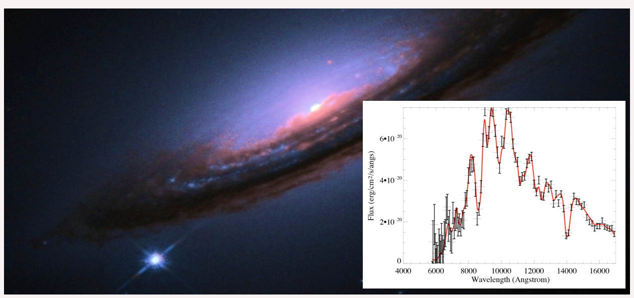
Supernova Survey

wide, medium, & deep imaging
+
IFU spectroscopy

2700 type Ia supernovae
z = 0.1–1.7

standard candle distances

z < 1 to 0.20% and z > 1 to 0.34%



High Latitude Survey

spectroscopic: galaxy redshifts

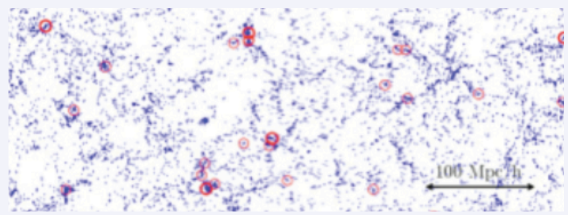
16 million Hα galaxies, z = 1–2
1.4 million [OIII] galaxies, z = 2–3

imaging: weak lensing shapes

380 million lensed galaxies
40,000 massive clusters

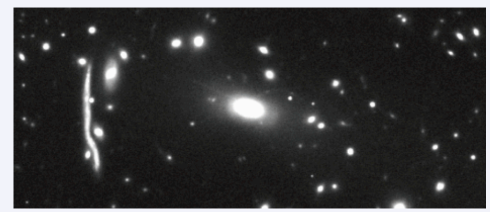
standard ruler

distances	expansion rate
z = 1–2 to 0.5%	z = 1–2 to 0.9%
z = 2–3 to 1.3%	z = 2–3 to 2.1%



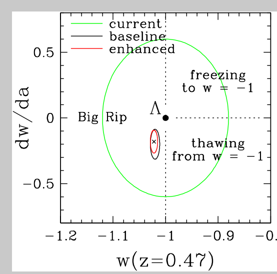
dark matter clustering

z < 1 to 0.21% (WL); 0.24% (CL)
z > 1 to 0.78% (WL); 0.88% (CL)
1.1% (RSD)



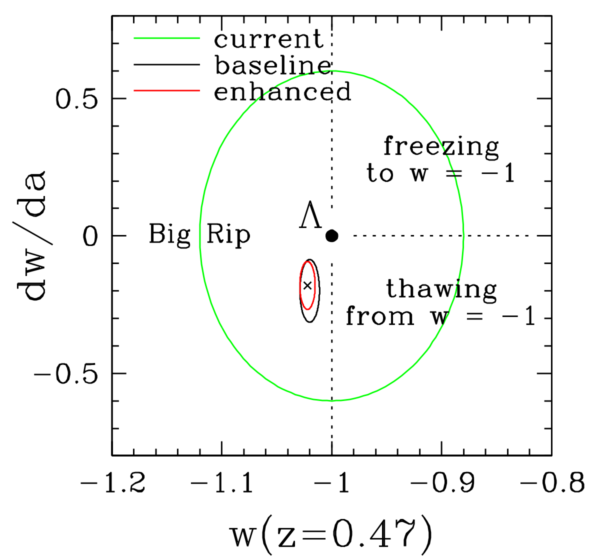
history of dark energy
+
deviations from GR

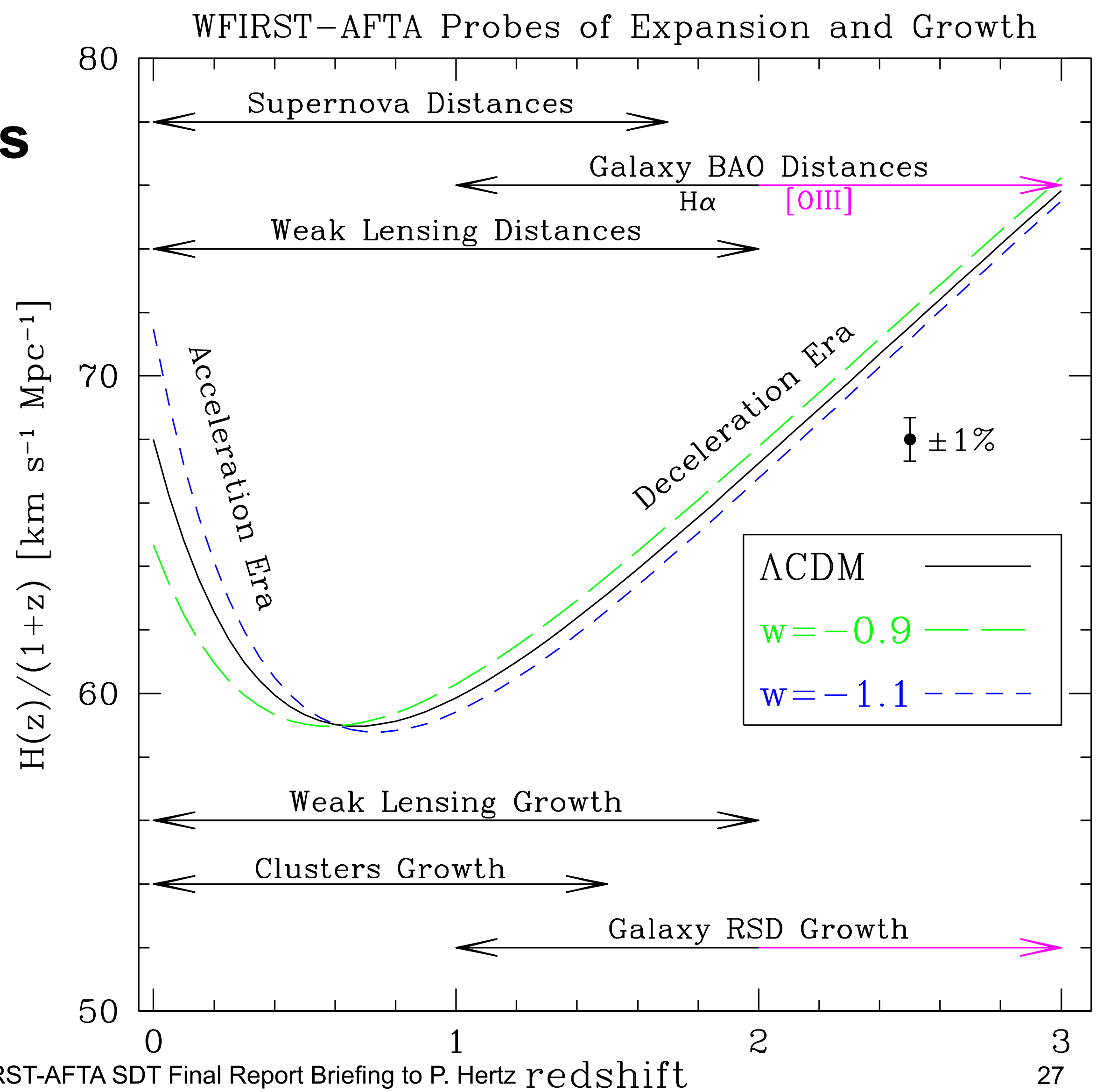
$w(z)$, $\Delta G(z)$, Φ_{REL}/Φ_{NREL}



Dark Energy Program

Multiple DE techniques to measure
- expansion history
- growth of structure

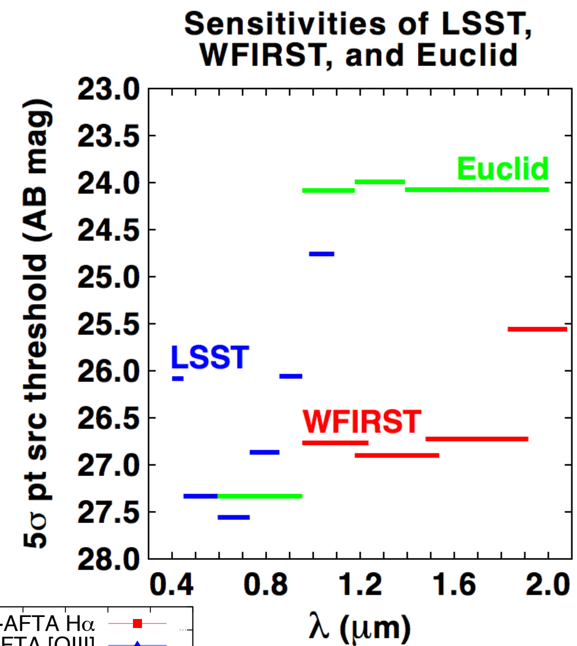




WFIRST-AFTA Dark Energy

Weak Lensing (2200 deg^2)

- High angular resolution
- Galaxy shapes in IR
- 380 million galaxies
- Photo-z redshifts
- 4 imaging filters

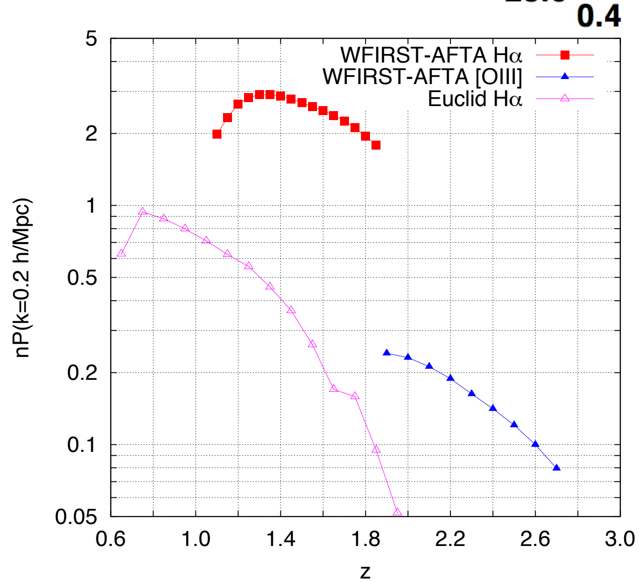


Supernovae

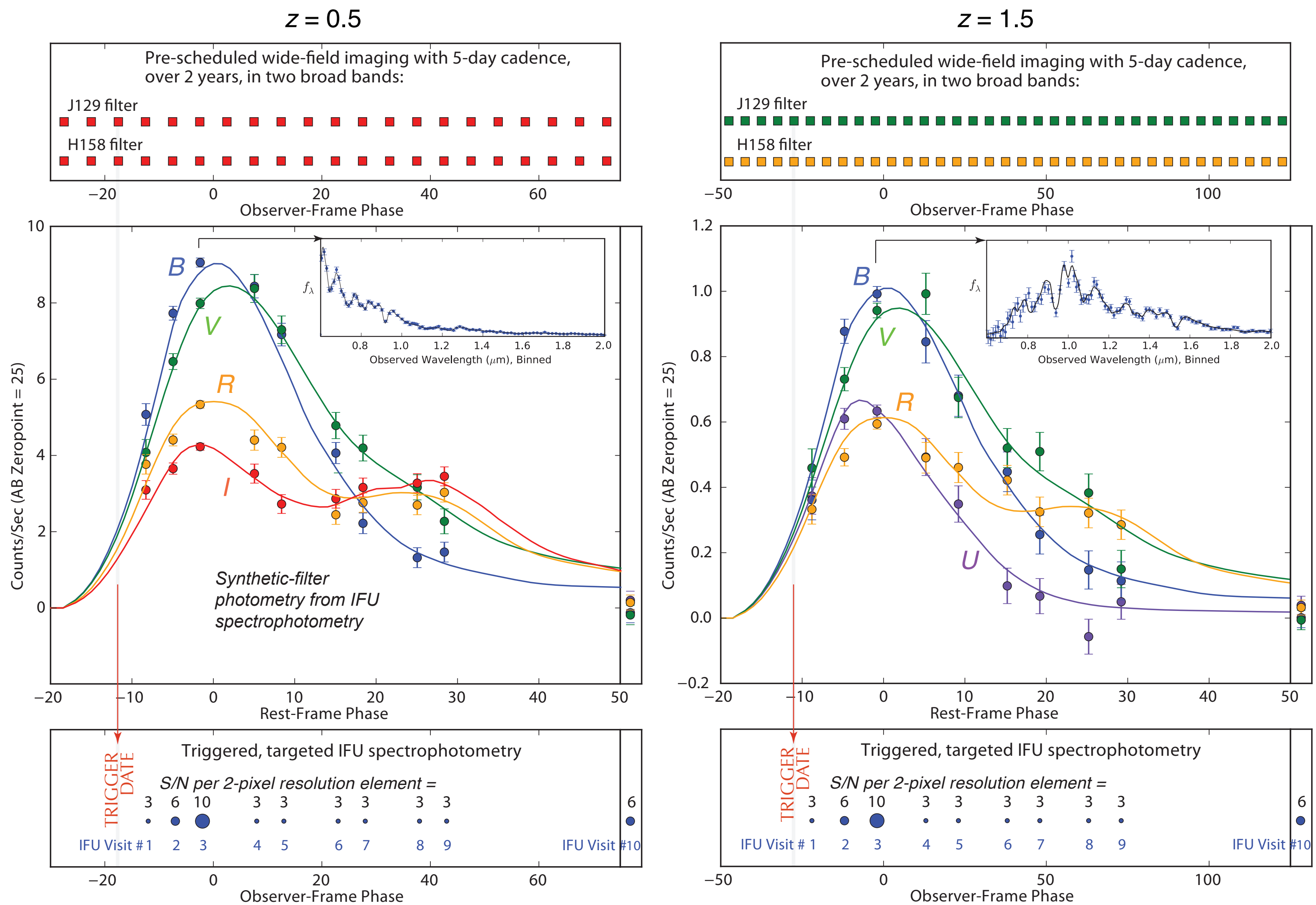
- High quality IFU spectra
- 5 day sampling of light curves
- 2700 SNe

Redshift survey (2200 deg^2)

- BAO & Redshift Space Distortions
- High number density of galaxies
- 16 million galaxies

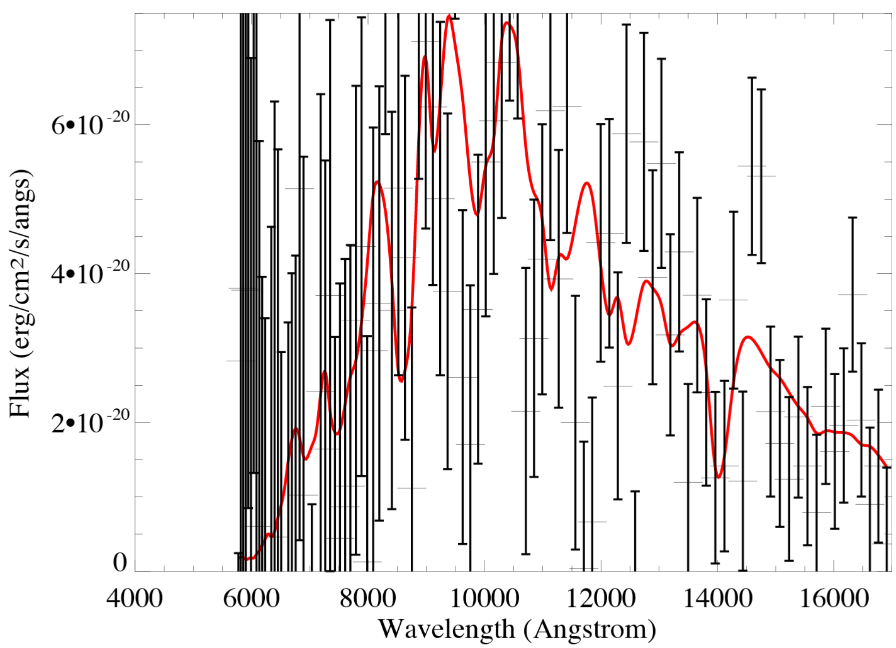


Supernova Observations

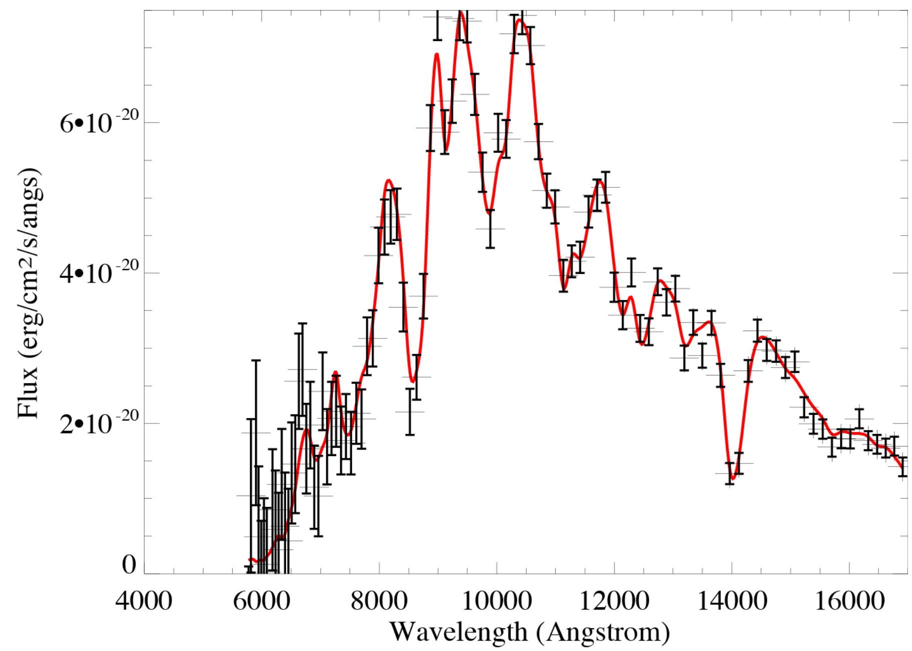


Supernova Spectra Comparison
Prism vs. IFU

S/N=1 with prism



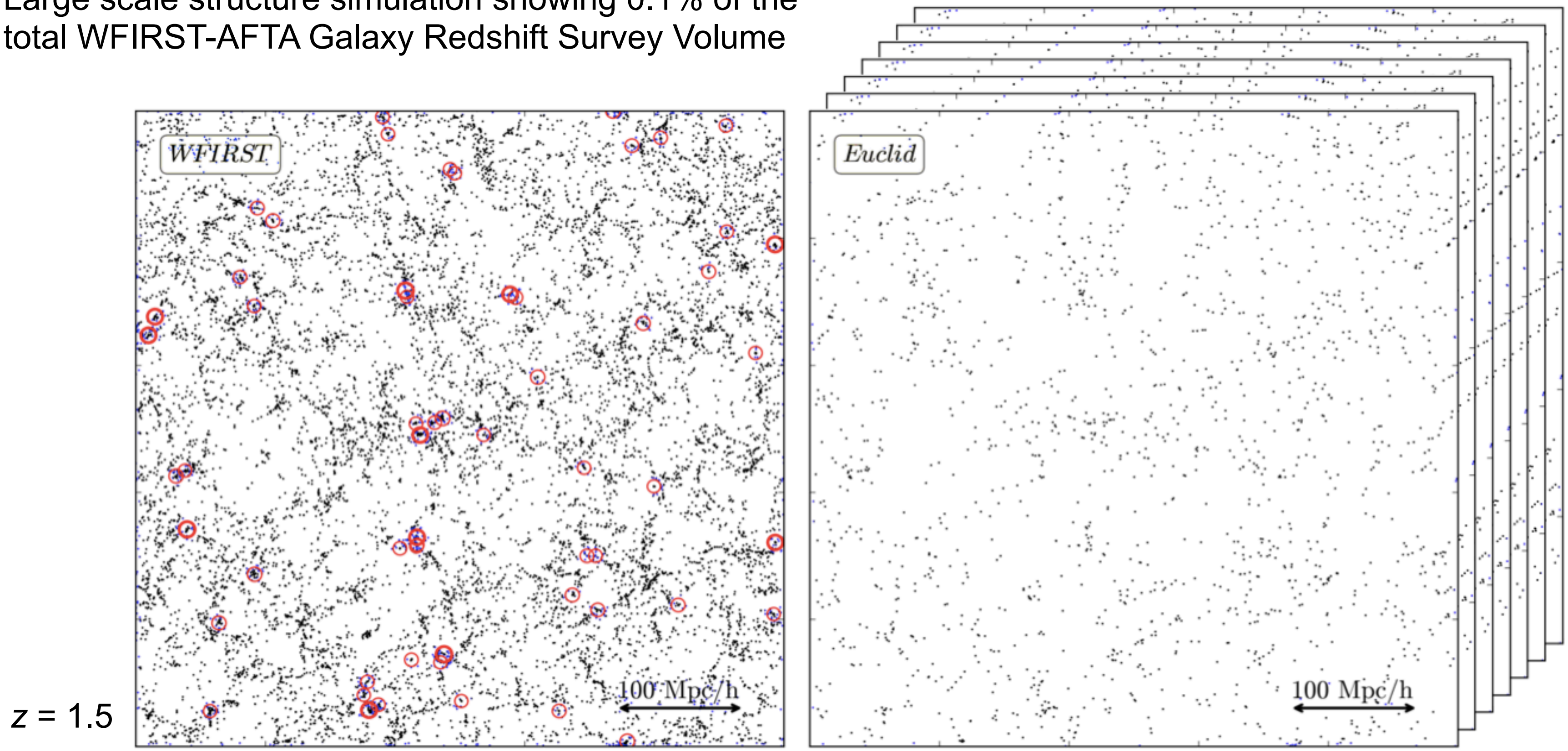
S/N=7 with IFU



SN Ia spectrum at z = 1.3

Detailed 3D Map of Large Scale Structure at z = 1-2

Large scale structure simulation showing 0.1% of the total WFIRST-AFTA Galaxy Redshift Survey Volume



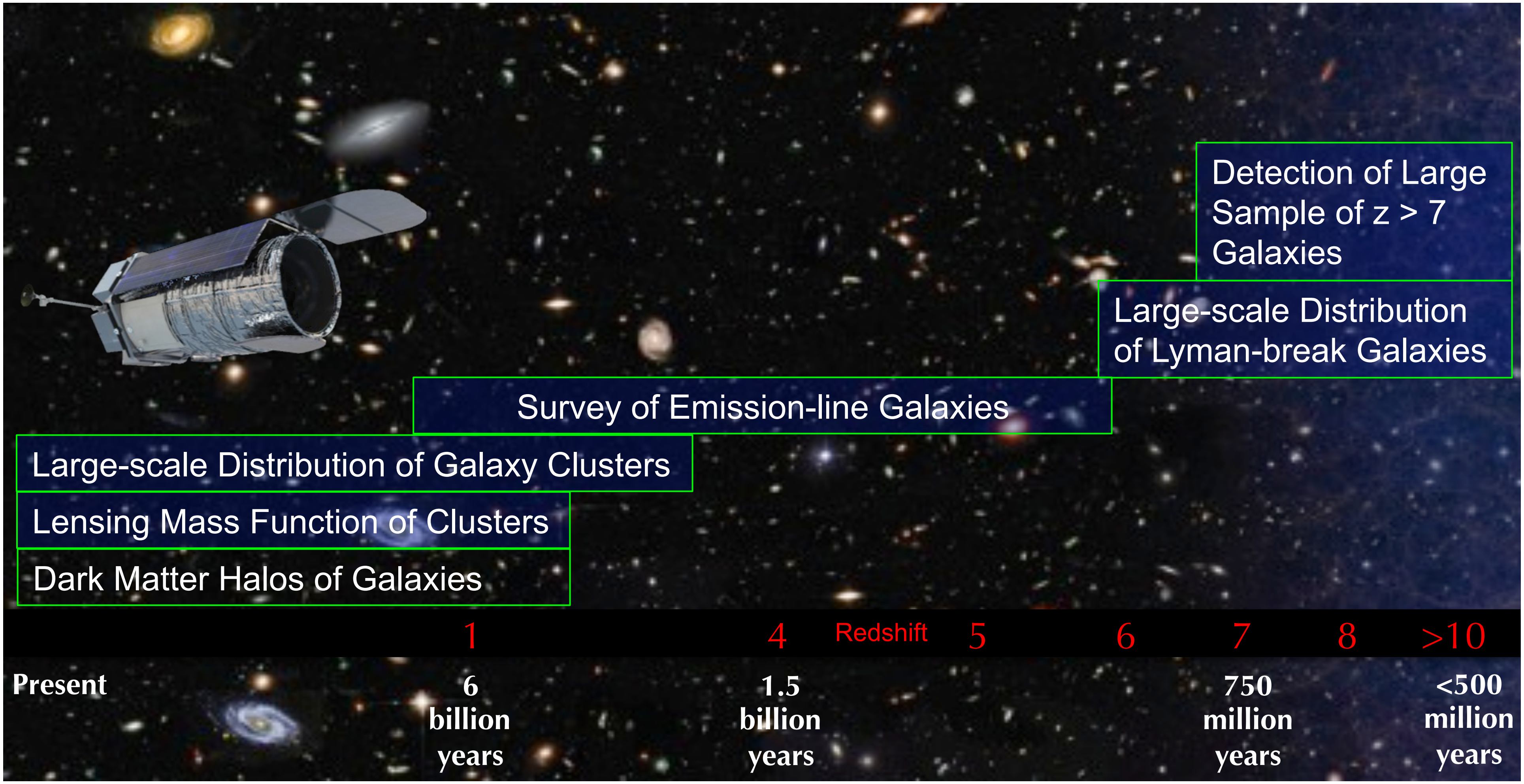
WFIRST
2,200 deg^2 @ 9 x 10^{-4} gal/Mpc^3

Euclid
15,000 deg^2 @ 1 x 10^{-4} gal/Mpc^3

Large scale structure simulations from 2015 SDT Report – courtesy of Ying Zu
Thin and thick red circles mark clusters with masses exceeding 5 x 10^{13} M_{Sun} and 10^{14} M_{Sun}, respectively

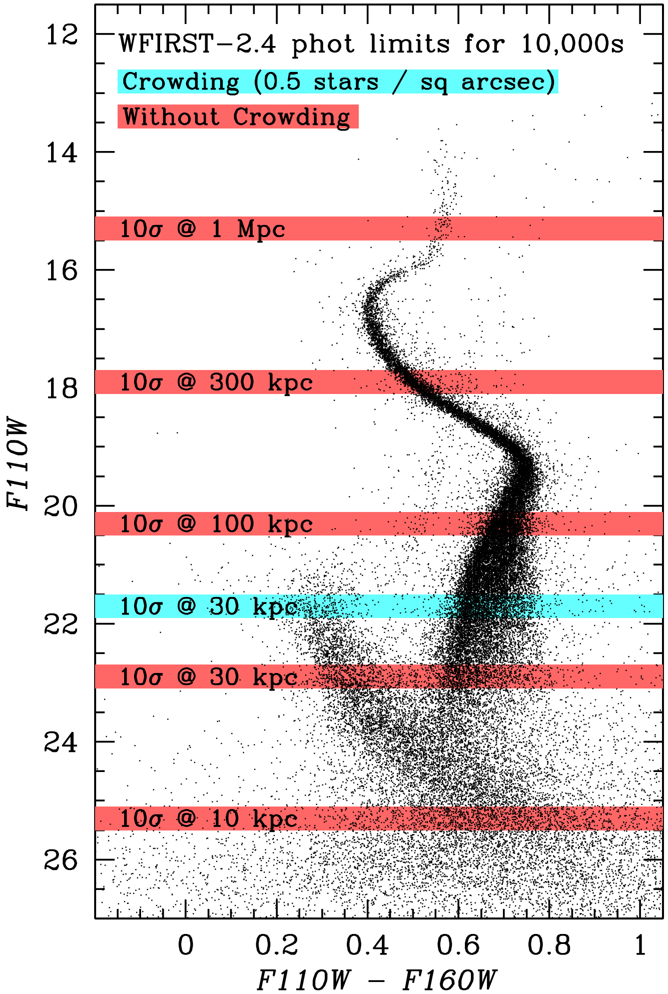
WFIRST-AFTA: A Unique Probe of Cosmic Structure Formation History

Using Observations from the High-Latitude Survey and GO Programs

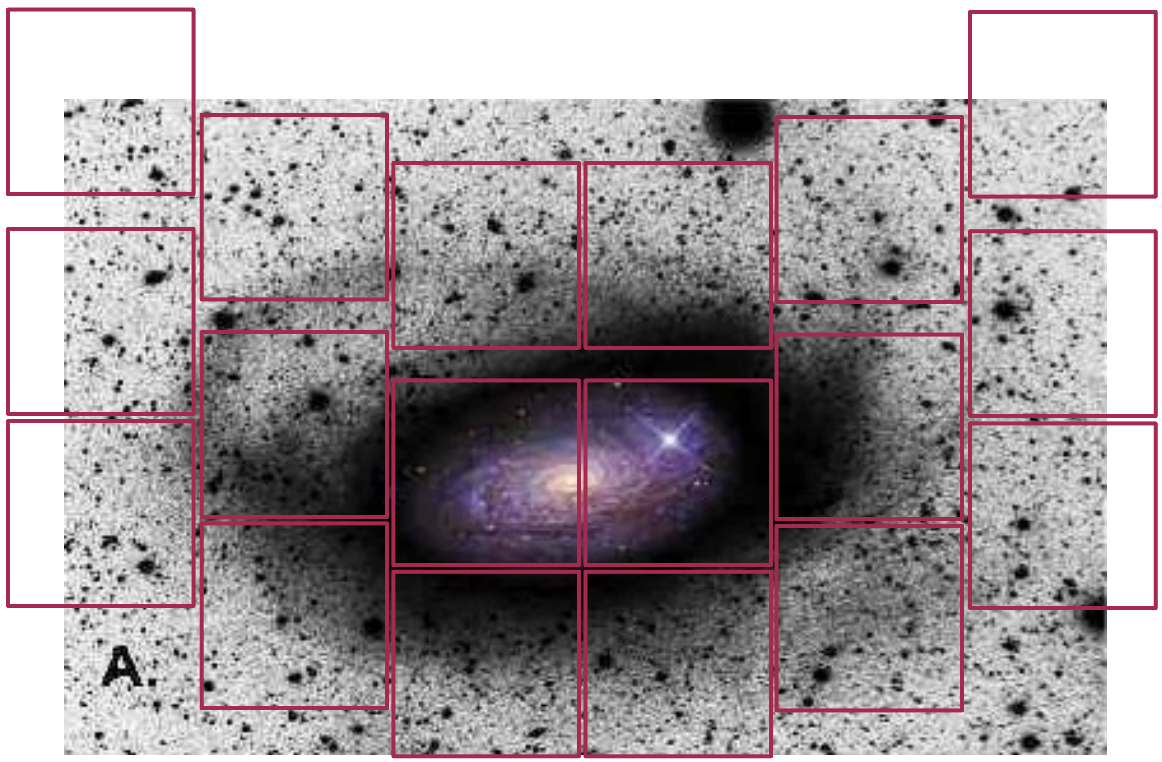


WFIRST-AFTA – A Unique Probe of Stellar Populations and Nearby Galaxies

Resolve and characterize stellar pops out to large distances (47 Tuc and SMC - Kalirai et al. 2012)

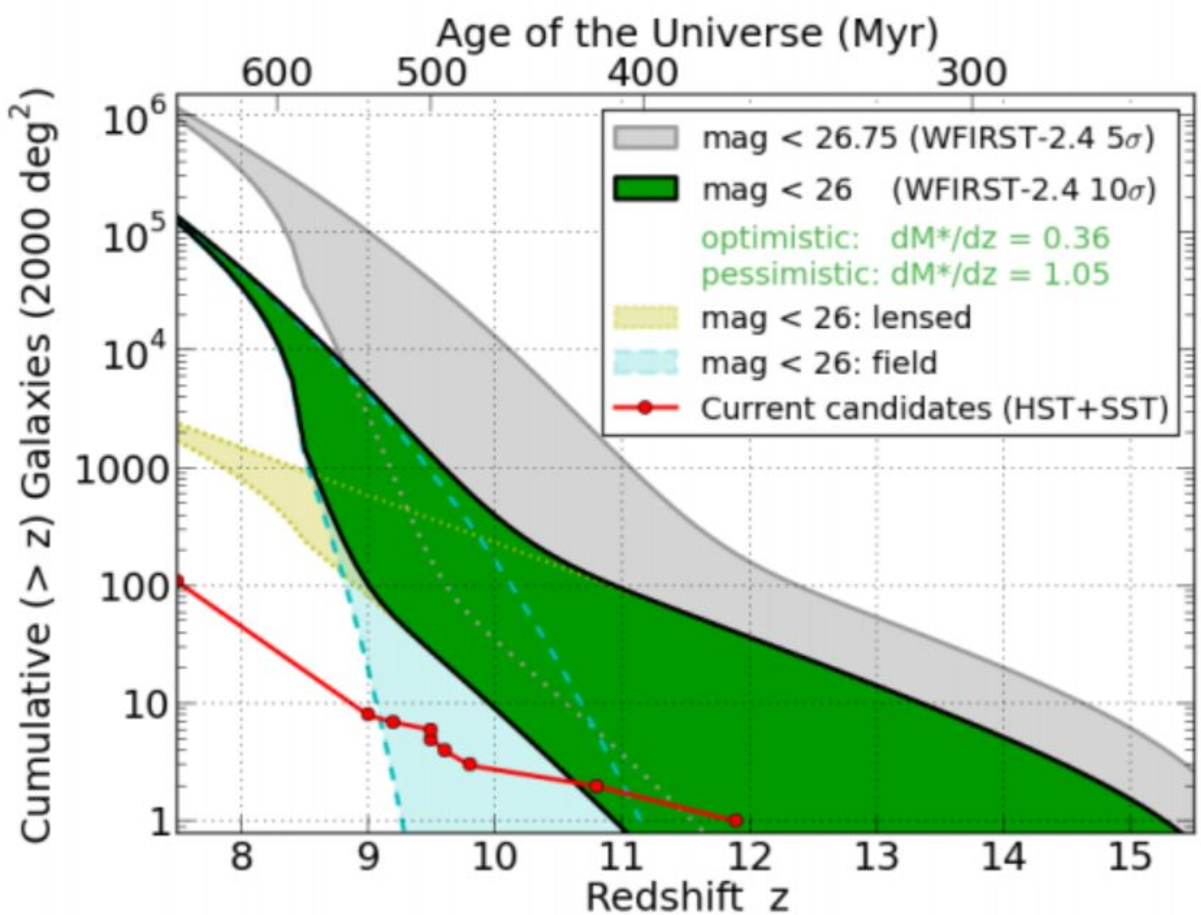


Ultra-deep imaging of galaxy halos (M63 - Martinez-Delgado et al. 2010)



Galaxy Luminosity Function

WFIRST's High-Latitude Survey will yield up to 2 orders of magnitude more high redshift galaxies than currently known



WFIRST-AFTA Exoplanet Science

The combination of microlensing and direct imaging will dramatically expand our knowledge of other solar systems and will provide a first glimpse at the planetary families of our nearest neighbors.

Microlensing Survey

Monitor 200 million Galactic bulge stars every 15 minutes for 1.2 years

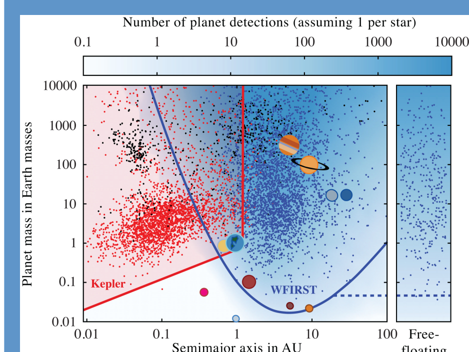
2600 cold exoplanets
370 Earth-mass planets
50 Mars-mass or smaller planets
30 free-floating Earth-mass planets

High Contrast Imaging

Survey up to 200 nearby stars for planets and debris disks at contrast levels of 10^{-9} on angular scales > 0.1”
R=70 spectra and polarization between 430-970 nm

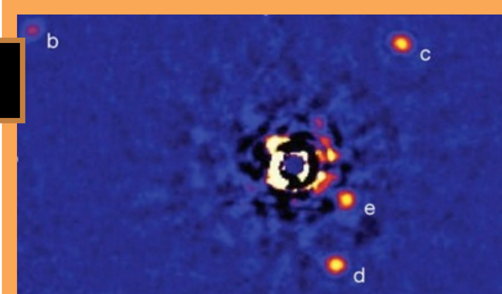
Detailed characterization of up to a dozen giant planets.
Discovery and characterization of several Neptunes
Detection of massive debris disks.

Complete the Exoplanet Census



- How do planetary systems form and evolve?
- What are the constituents and dominant physical processes in planetary atmospheres?
- What kinds of unexpected systems inhabit the outer regions of planetary systems?
- What are the masses, compositions, and structure of nearby circumstellar disks?
- Do small planets in the habitable zone have heavy hydrogen/helium atmospheres?

Discover and Characterize Nearby Worlds



Toward the "Pale Blue Dot"

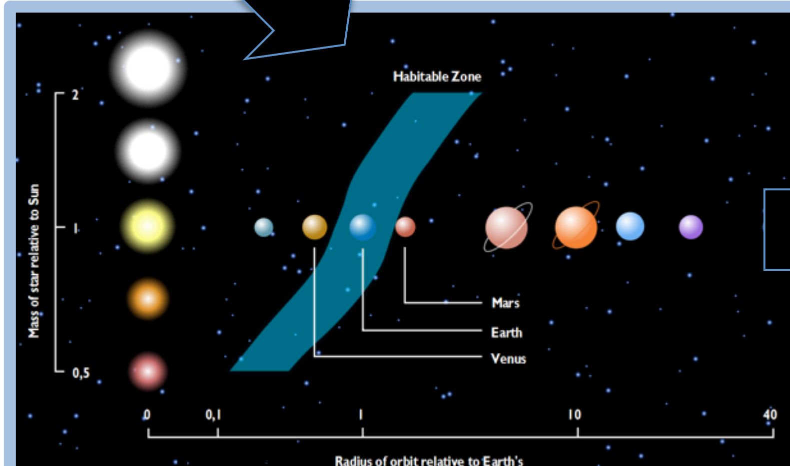
WIFRST will lay the foundation for a future flagship direct imaging mission capable of detection and characterization of Earth-like planets.

Microlensing Survey

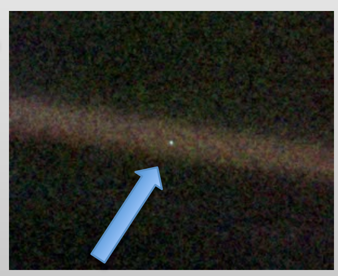
- Inventory the outer parts of planetary systems, potentially the source of the water for habitable planets.
- Quantify the frequency of solar systems like our own.
- Confirm and improve Kepler's estimate of the frequency of potentially habitable planets.
- When combined with Kepler, provide statistical constraints on the densities and heavy atmospheres of potentially habitable planets.

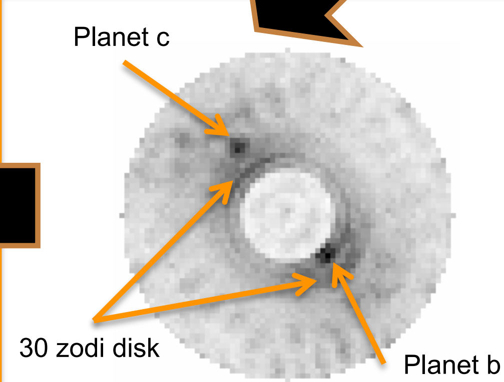
High Contrast Imaging

- Provide the first direct images of planets around our nearest neighbors similar to our own giant planets.
- Provide important insights about the physics of planetary atmospheres through comparative planetology.
- Assay the population of massive debris disks that will serve as sources of noise and confusion for a flagship mission.
- Develop crucial technologies for a future mission, and provide practical demonstration of these technologies *in flight.*



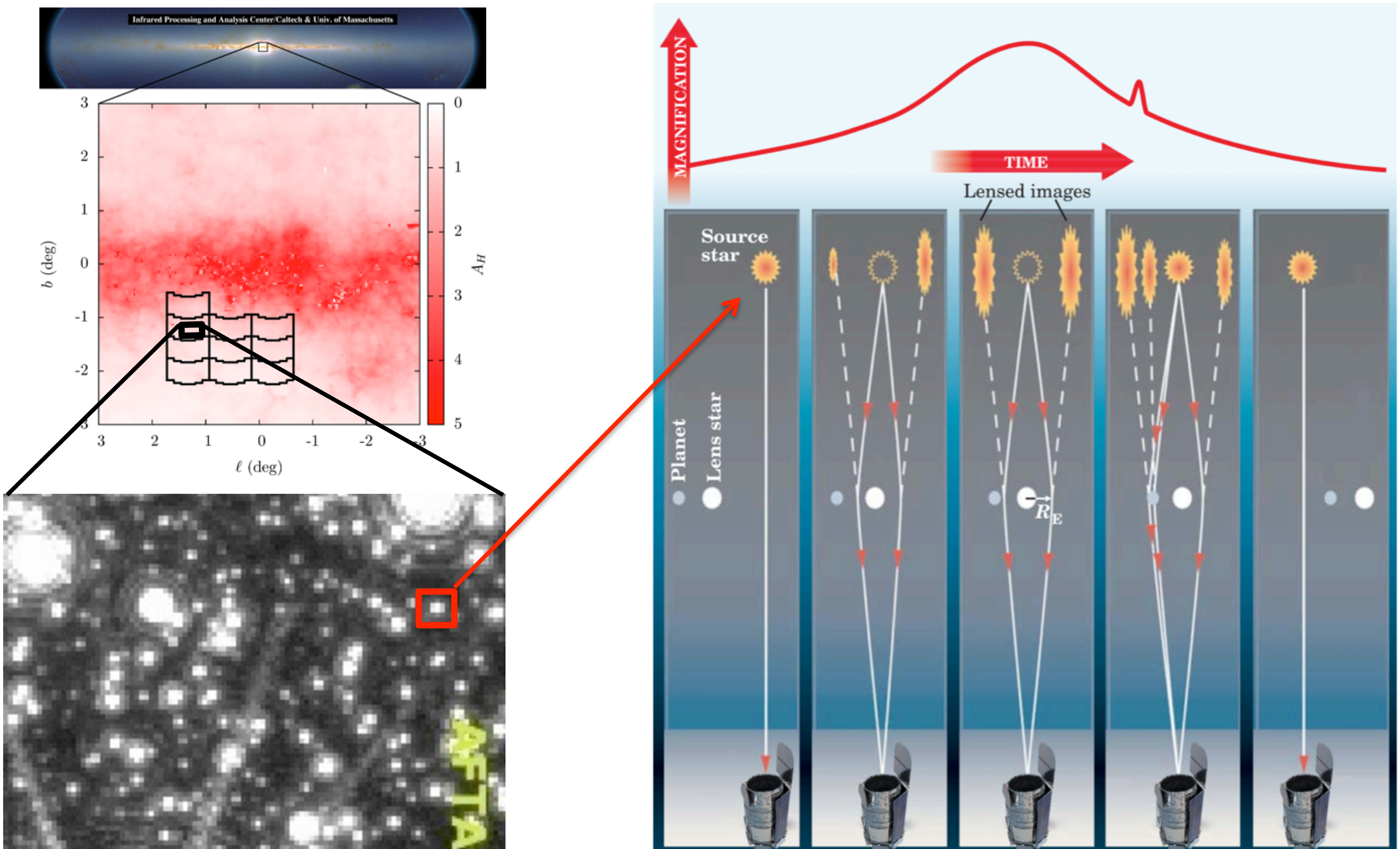
Science and technology foundation for the New Worlds Mission.





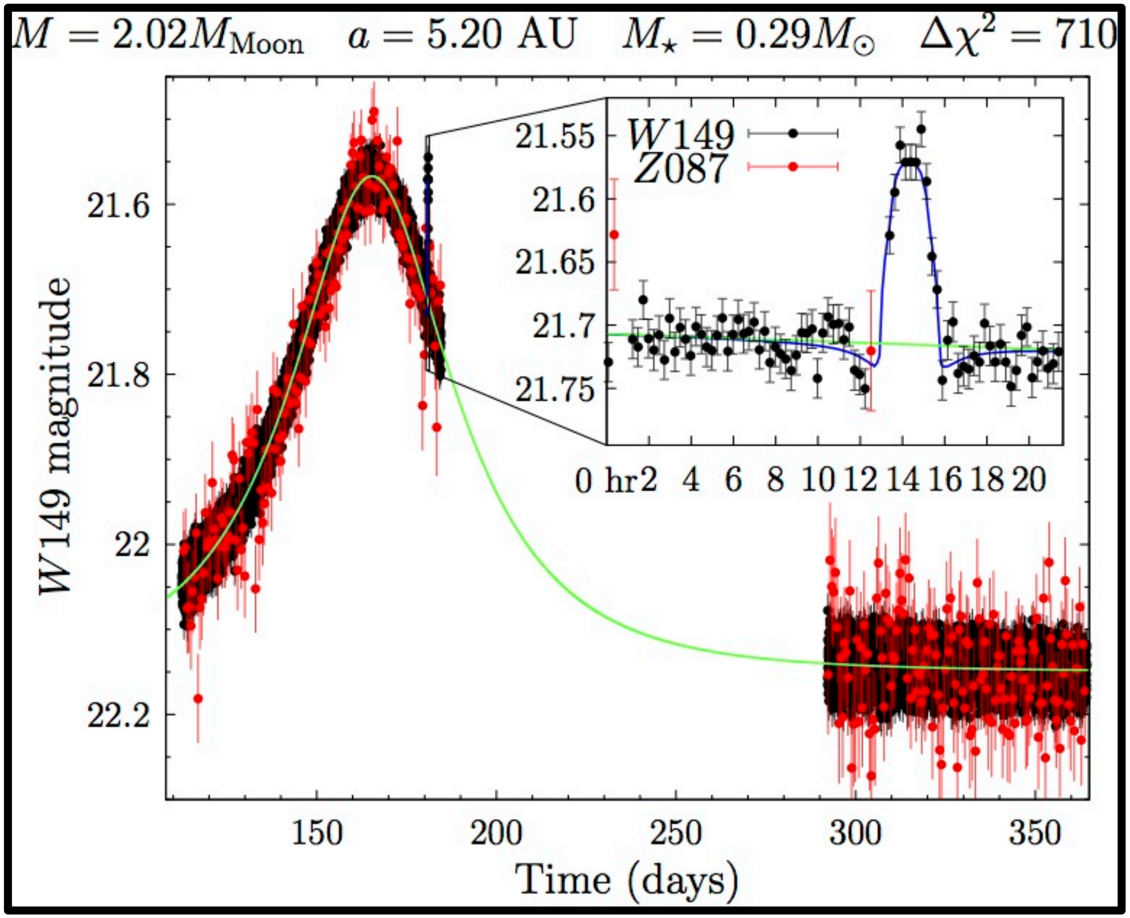
Simulated WFIRST-AFTA coronagraph image of the 47 UMa planetary system

Microlensing Technique

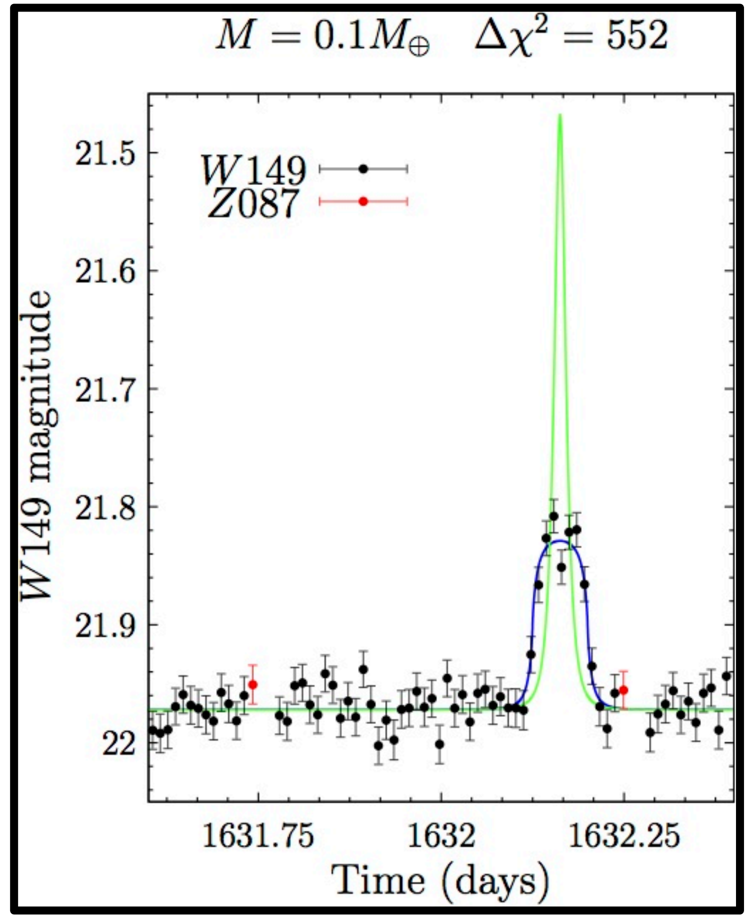


Great benefit of space observations in the crowded galactic bulge field

Exquisite Sensitivity to Cold, Low Mass, and Free Floating Planets

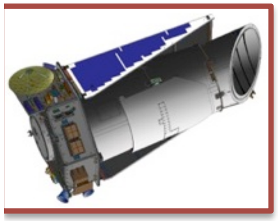


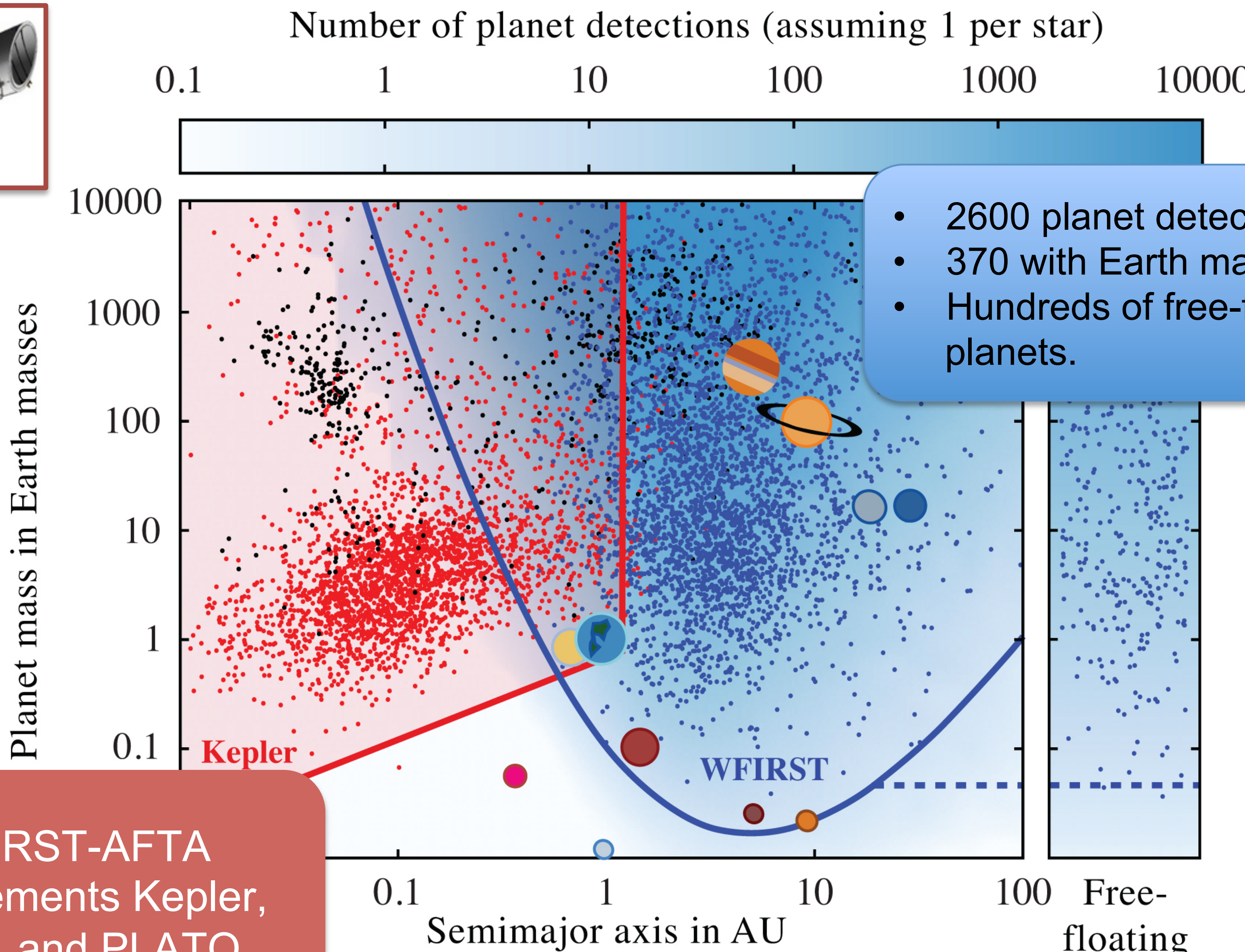
2 x Mass of the Moon @ 5.2 AU
(~27 sigma)

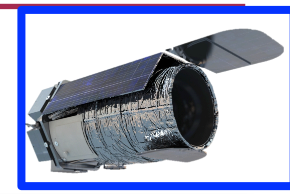


Free floating Mars
(~23 sigma)

Exoplanet Surveys
Kepler & WFIRST





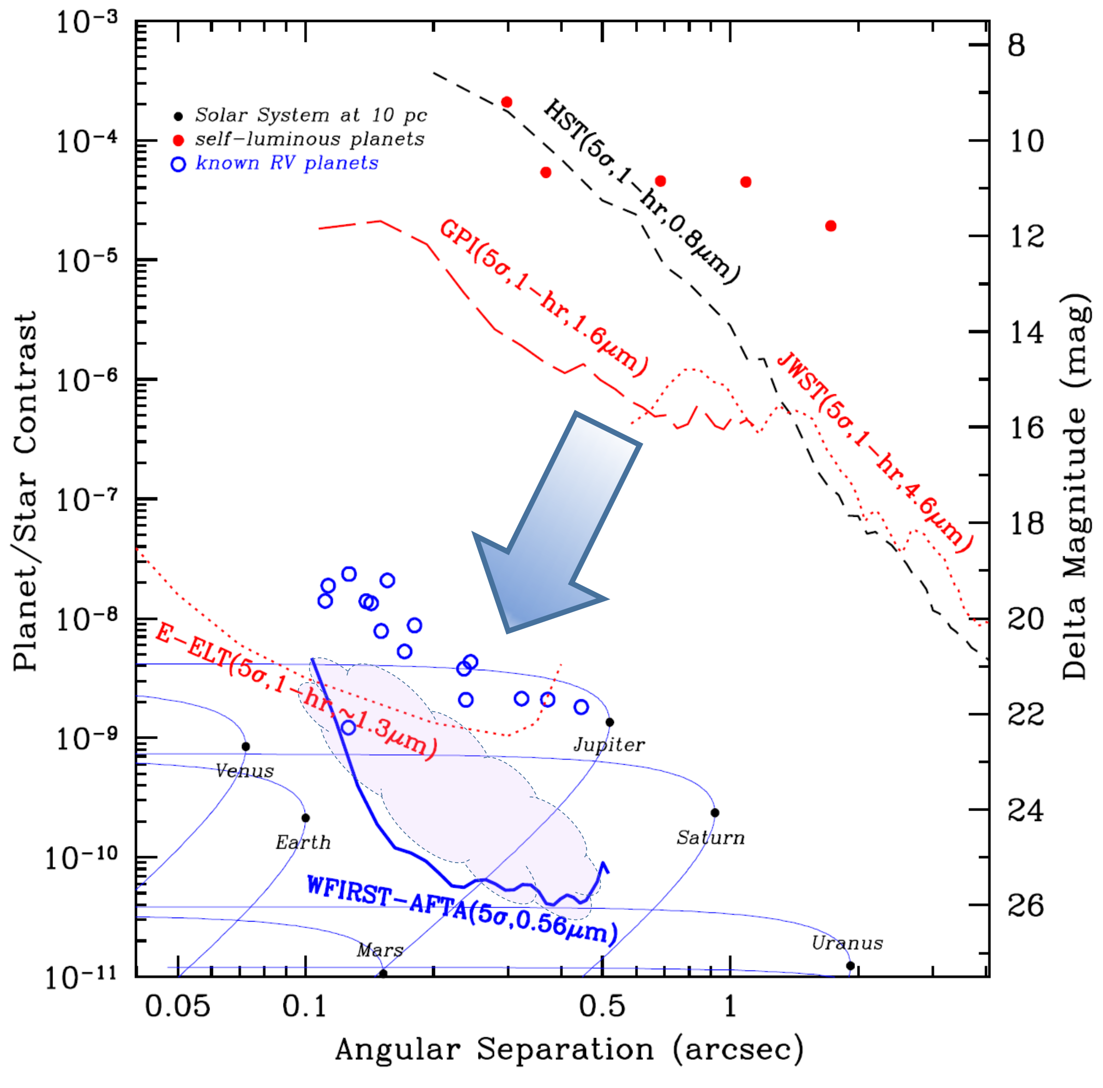


- 2600 planet detections.
- 370 with Earth mass and below.
- Hundreds of free-floating planets.

WFIRST-AFTA complements Kepler, TESS, and PLATO.

WFIRST-AFTA Brings Humanity Closer to Characterizing exo-Earths

- WFIRST-AFTA advances many of the key elements needed for a coronagraph to image an exo-Earth
  - ✓ Coronagraph
  - ✓ Wavefront sensing & control
  - ✓ Detectors
  - ✓ Algorithms



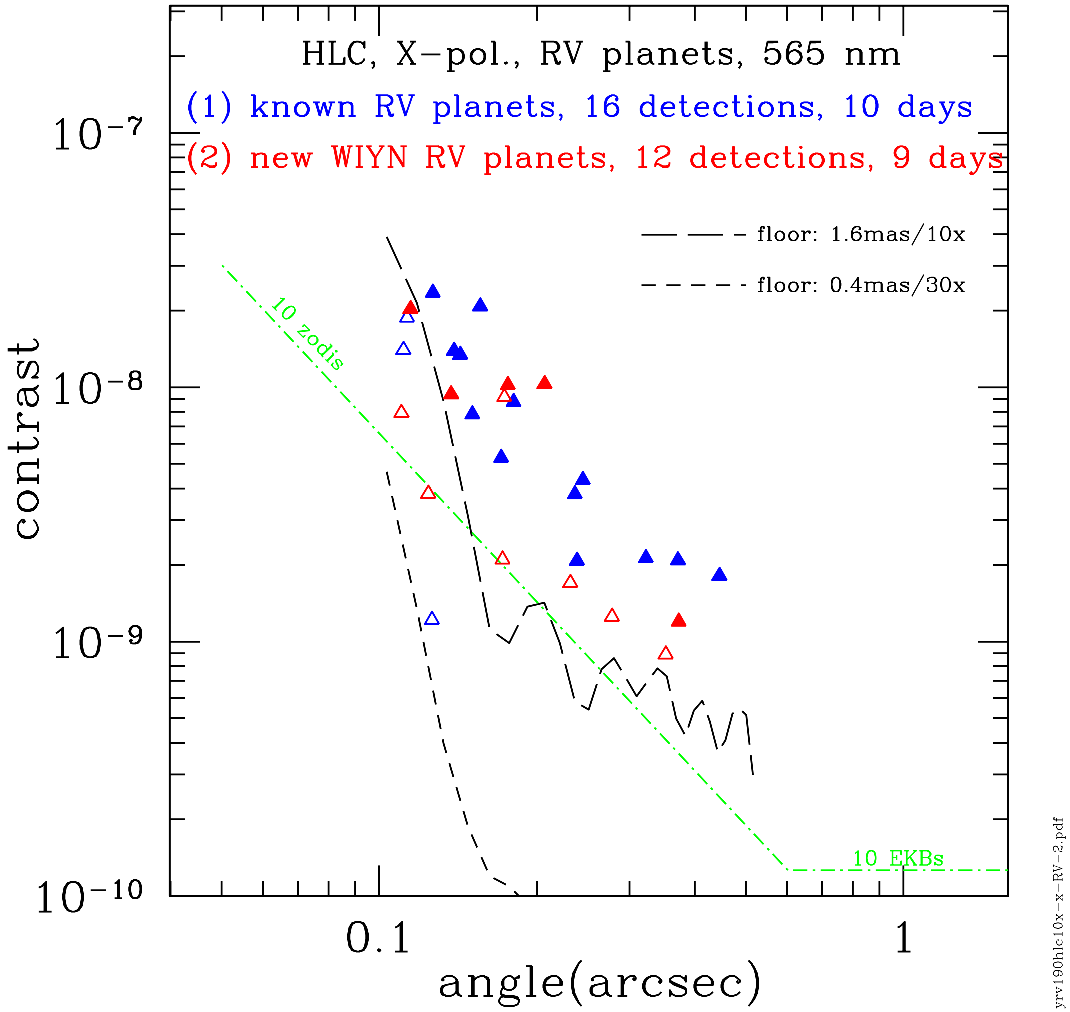
Exoplanet Yield Estimates

	Giants (4-15 R_E)	Sub-Neptunes (2-4 R_E)	Super-Earths (1-2 R_E)	Total
Known RV Studies*	16	0	0	16
180-day Blind Search	2	6	4	12
Total**	18	6	4	28

* RV yield will be augmented by the WIYN program for future RV observations
** Yield assumes 0.4 jitter and 30x speckle attenuation

Exoplanet Yield Estimates

New detections of (1) known RV exoplanets & (2) new exoplanets to be found with the aid of WIYN RV observations



WFIRST-AFTA Significantly Expands the Population of Characterized Planets

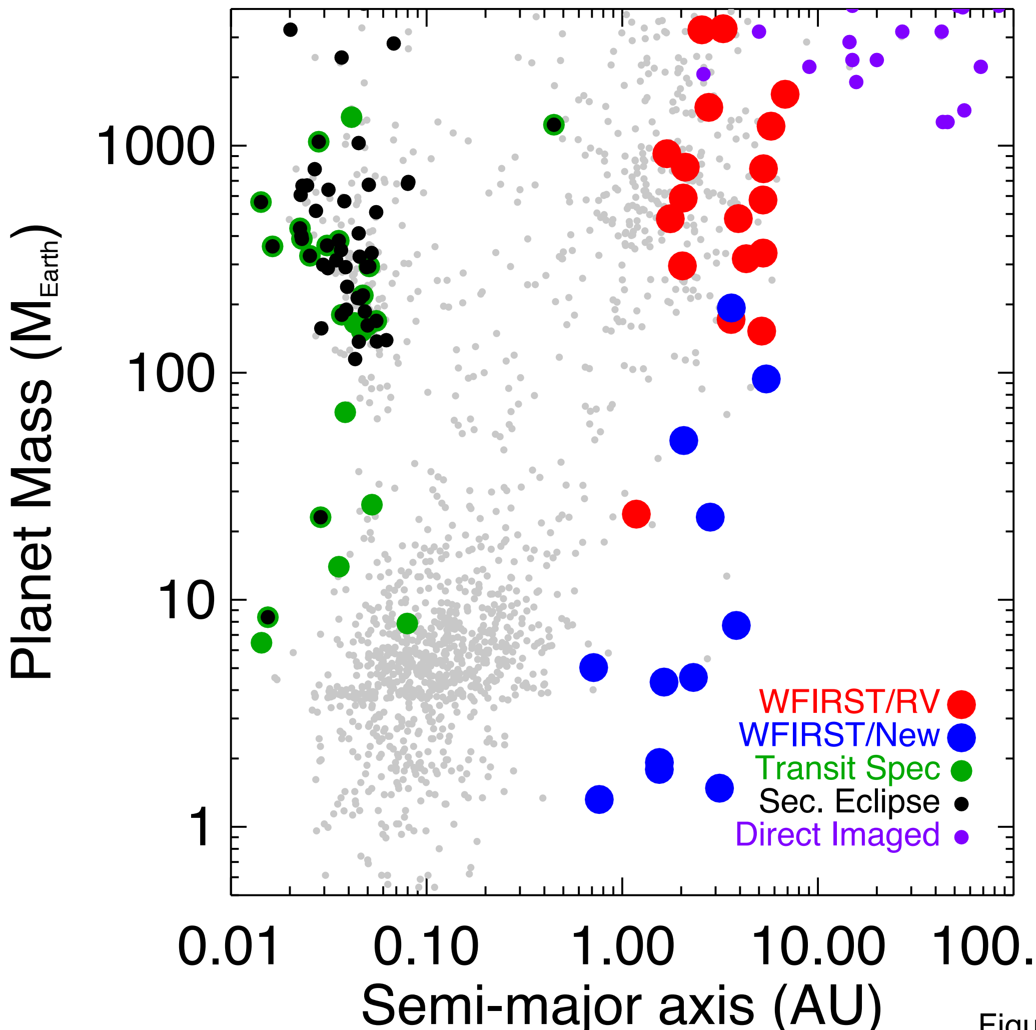


Figure credit Eric Nielsen

Foreign Interest in WFIRST-AFTA

Interests by Foreign Groups for Potential Contributions

- Japan
  - WFI: Could provide coordinated ground-based observations (wide and deep spectroscopy and deep optical imaging) and microlensing/galactic bulge science imaging processing pipeline & precursor ground observations
  - CGI: Interested in a polarization module, mask fabrication, analysis/algorithm support, PIAA module
- Canada
  - Strong science interest in SN and WL surveys as well as coronagraphy
  - WFI: Interested in the IFU, FGS, photometric calibration (pre-flight or flight), UV/blue wide-field instrument
  - CGI: Interested in the IFS, EMCCDs, LOWFS, filter/mask wheels, data reduction pipeline, data processing, and archiving
- UK and Europe
  - WFI: Interested in the IFU and opto-mechanical systems and associated electronics, ground processing of spectroscopy data, image/data processing and analysis pipeline, lenses and mounts, and calibration hardware
  - CGI:
    - Expertise in flight instruments, high contrast test bed for testing coronagraphs and post-coronagraphic techniques and detector technology
    - Interested in LOWFS design, optical element, CCDs and associated camera
- Korea
  - No formal statement in the report, discussions are at the very early stages, but strong interest & possible funding, likely centered around the HgCdTe detectors

Initial Thoughts on Foreign Contributions

- WFI
  - IFU: Canada, Europe
  - FGS: Canada
  - Opto-Mechanical Systems: Europe
  - Calibration system: Canada, Europe
  - Data Processing: Canada, Europe, Japan
  - Ground-based observations: Europe, Japan
- CGI
  - IFS: Canada
  - Detectors: Canada, UK
  - Filter/mask wheels: Canada
  - Operational algorithms: Japan
  - Polarization module: Japan

Study Office is preparing a recommendation that balances the advantages with the associated risks

Science Team Selection Process and Data Rights

Future Science Working Group

Typically 15-20 members

- Project Science team (from NASA Centers)
  - Project, Instrument, Telescope, and Detector Scientists
- Science center leads
- PIs of selected investigations / instruments
- Interdisciplinary scientists (IDSs) representing GI and GO programs & community
- EPO scientist
- Program Scientist (from HQ, ex-officio)
- Foreign representatives

Options for SWG Selection

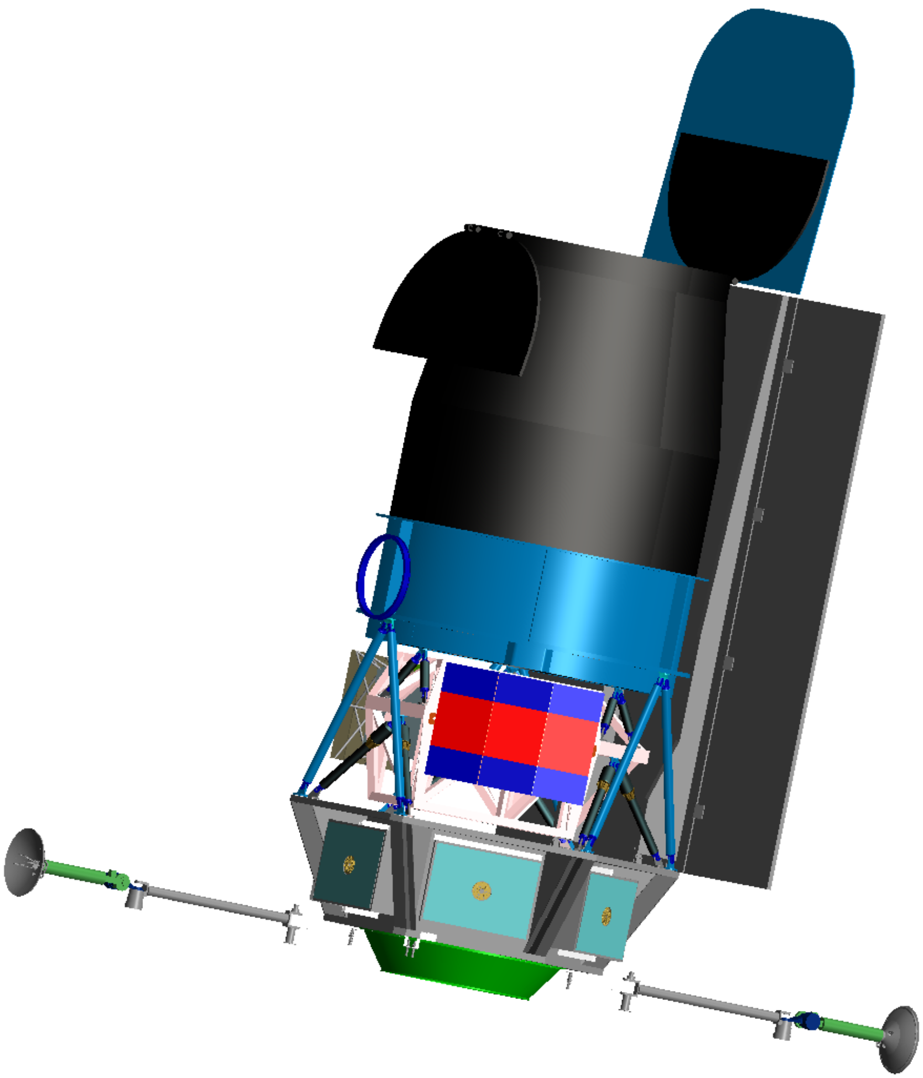
- If instruments are provided by NASA, scientific investigations and interdisciplinary scientists would be selected
- Assume 8 investigations and 3 IDSs
- Option A:
  – 4 investigations for IR survey
  – 4 investigations for exoplanets
- Option B:
  – 1 investigation **each** for WL, BAO, SNe
  – 1 investigation for non-DE survey science
  – 1 investigation for microlensing
  – 1 investigation for astrophysics in the microlensing field
  – 1 or 2 investigations for exoplanet coronagraph
  – 1or 2 investigations for debris disks

Data Rights Considerations

- Standard of 1 year proprietary time for all data is probably no longer acceptable to NASA or the community
- WFIRST-AFTA wide field imager has wide FoV that makes proprietary data difficult
- Different science areas for WFIRST-AFTA have different data needs and processing requirements.
- An open data policy such as that of LSST and Fermi LAT may be the natural fit for most or all of the WFIRST-AFTA data
- Rapid public access to broad-use survey data has been demonstrated to maximize scientific output.
- Will the 1 year of coronagraph science be determined by a selected science team or by GOs or by a combination?

Observatory Overview

WFIRST-AFTA Observatory Concept



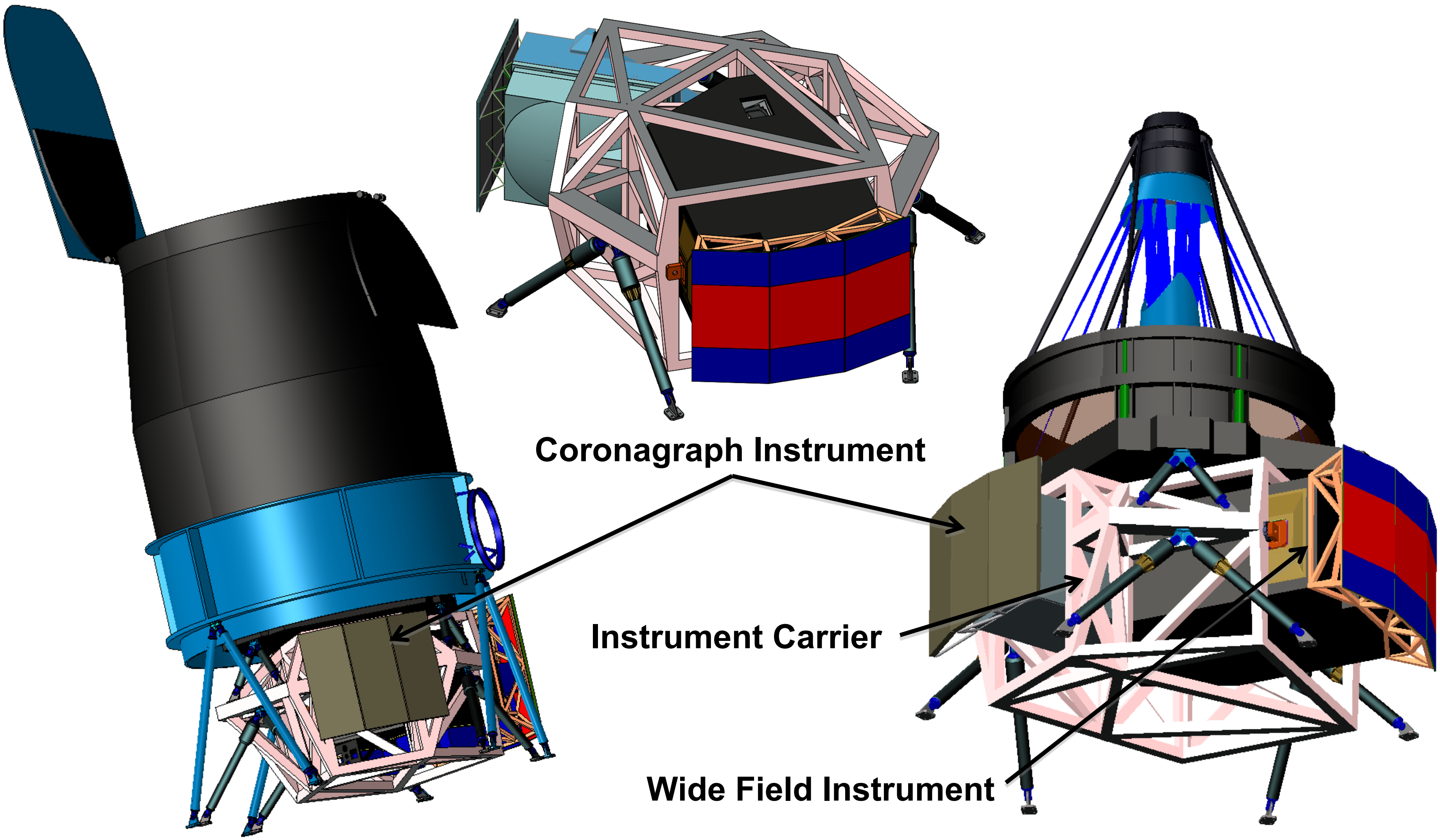
Key Features

- **Telescope:** 2.4 m aperture primary mirror
- **Instruments**
  - Wide Field Imager/Spectrometer & Integral Field Unit
  - Internal Coronagraph with Integral Field Spectrometer
- **Overall Dry Mass:** 4059 kg (CBE)
- **Structure:** high stiffness composites; modular packaging for avionics
- **GN&C/Propulsion:** inertial pointing, 3-axis stabilized, mono-prop system for stationkeeping & momentum unloading
- **Data Downlink Rate:** Continuous 600 Mbps Ka-band to dedicated ground station
- **C&DH:** low rate bus for housekeeping and spacecraft control, high speed bus for science data
- **Power:** ~2400 W average power (CBE)
- **GEO orbit**
- **Launch Vehicle:** Delta IV Heavy
- **GSFC:** leads mission, wide field instrument, spacecraft
- **JPL:** leads telescope, coronagraph

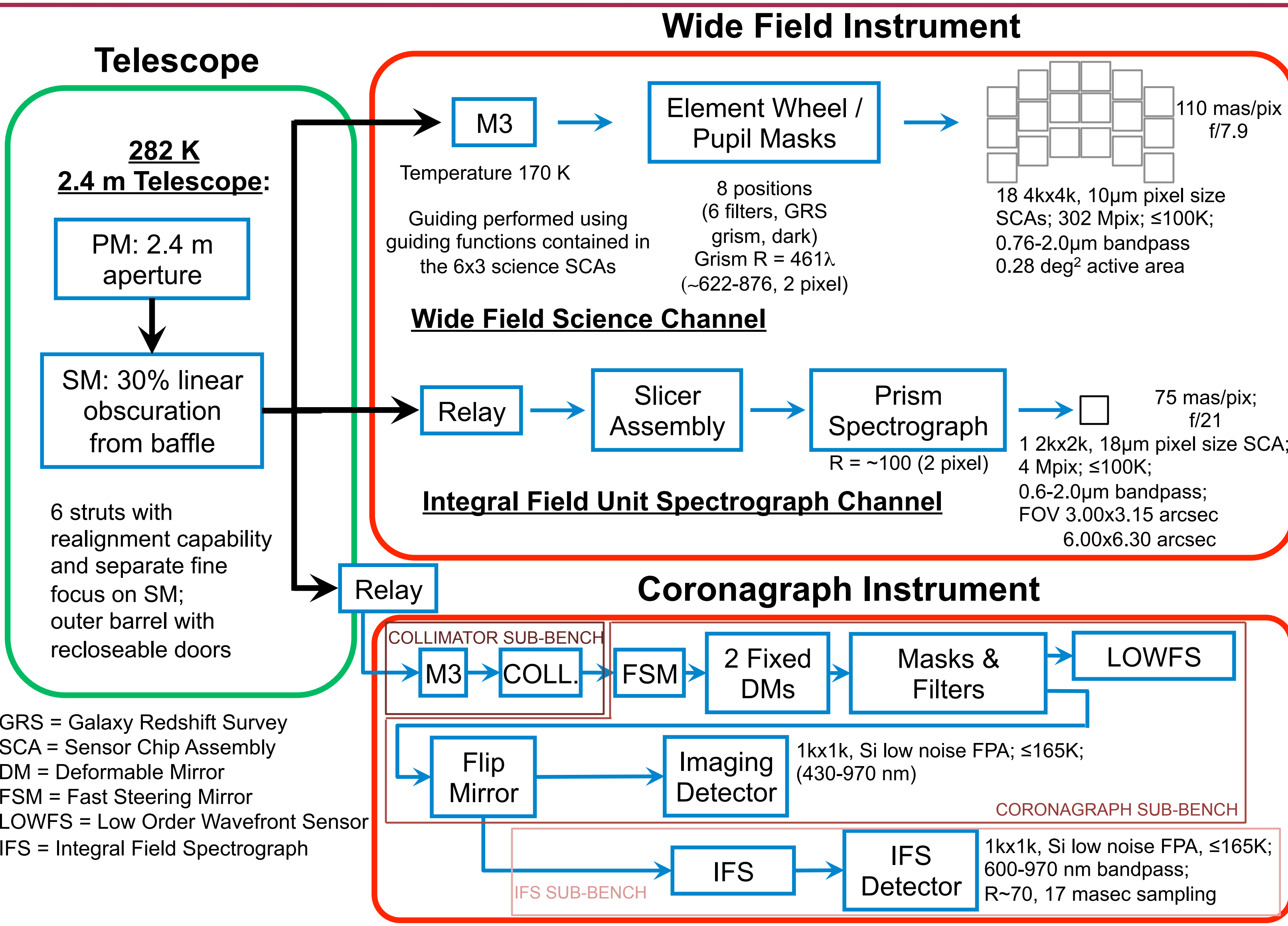
Changes Since 2013 Report

- Coronagraph is now part of the baseline as a Technology Demonstration instrument.
  - Was considered optional in the last report and not part of the CATE
  - As a tech demo, it is not allowed to drive the mission requirements/schedule or cost (e.g. pointing)
- Telescope temperature is now set at 282K. This is within the qualification limits of the original program.
  - Operating temperature at prior CATE was 270K, outside of the original program survival limits
  - SDT has assessed the science impact and stated only slight degradation at warmer temperature. Slightly less depth for the same exposure time.
- Cryocooler added to Wide Field Instrument.
  - Detector operating temperature reduced from 120K to 100K based on recent detector testing – lower temperature necessary to meet WFIRST requirements.
  - Low jitter Turbo Brayton cooler allows colder operational temperatures than can be achieved passively in GEO orbit while minimizing jitter.
- Baseline launch vehicle is now a heavy lift vehicle
  - Allowed removal of the large bi-prop system and ~3000 kg of fuel and use a smaller mono-prop system.
  - Reduces size of spacecraft and provides significant mass margin.

WFIRST-AFTA Payload Layout



WFIRST-AFTA
Payload Optical Block Diagram

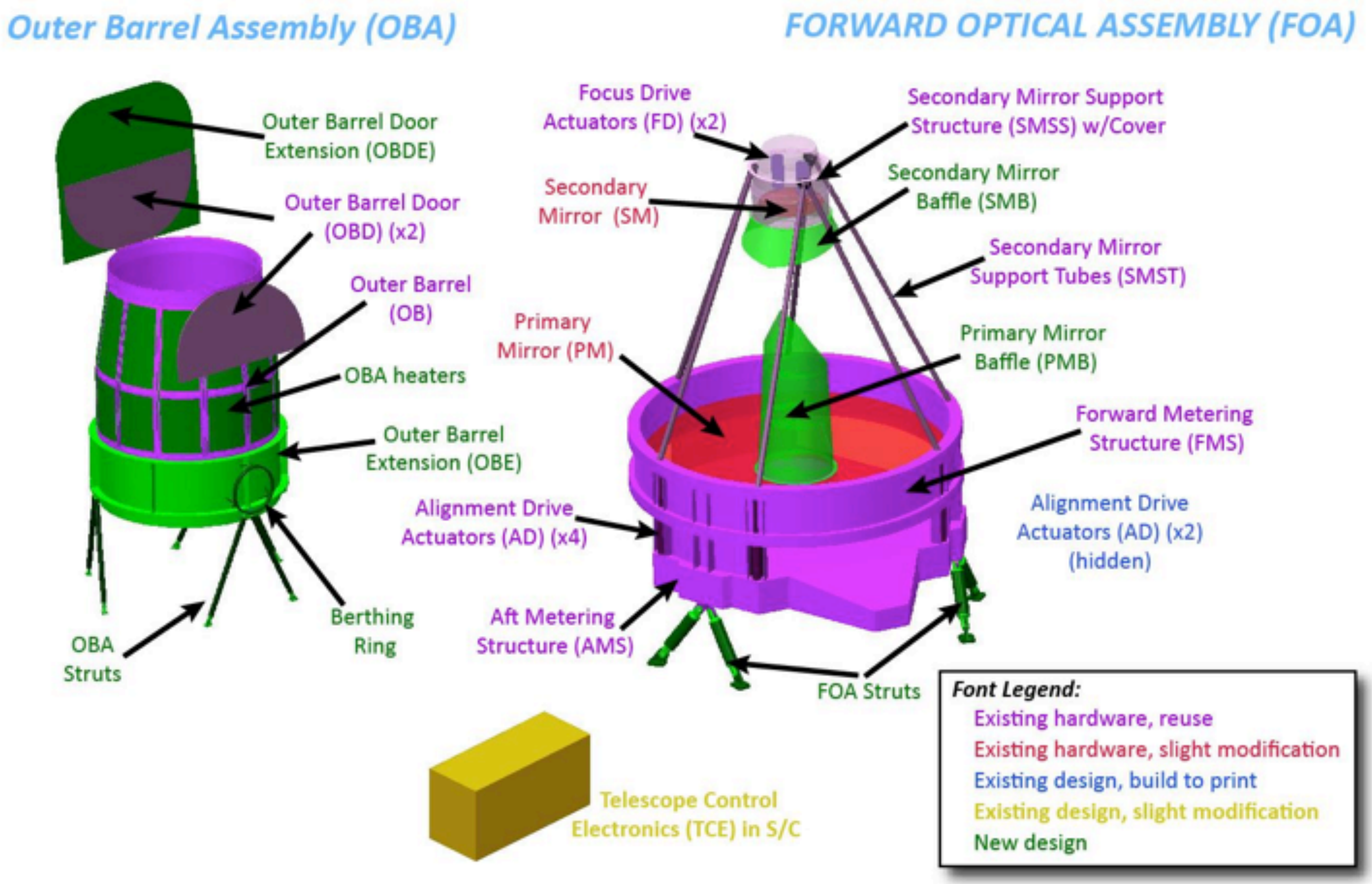


GRS = Galaxy Redshift Survey
SCA = Sensor Chip Assembly
DM = Deformable Mirror
FSM = Fast Steering Mirror
LOWFS = Low Order Wavefront Sensor
IFS = Integral Field Spectrograph

Mass Summary

	CBE Mass (kg)	Cont. (%)	CBE + Cont. (kg)
Wide Field Instrument	489	30	636
Coronagraph Instrument	120	30	156
Telescope	1582	11	1763
Spacecraft (includes IC)	1868	30	2428
Observatory (dry)	4059	23	4983
Propellant (3s)	107		122
Observatory (wet)	4166		5105
Delta IV Heavy Lift Capacity			6750

Telescope Reuse



Telescope Overview

- Two, 2.4 m, two-mirror telescopes provided to NASA. Built by Exelis.
  - Ultra Low Expansion (ULE®) glass mirrors
  - All composite structure
  - Secondary mirror actuators provide 6 degree of freedom control
  - Additional secondary mirror fine focus actuator
  - Active thermal control of structure
  - Designed for operation at room temperature (293 K) with survival temperature of 277 K, OBA survival temperature of 216 K
  - Outer barrel includes recloseable doors
  - Passive damping via D-struts at the spacecraft interface

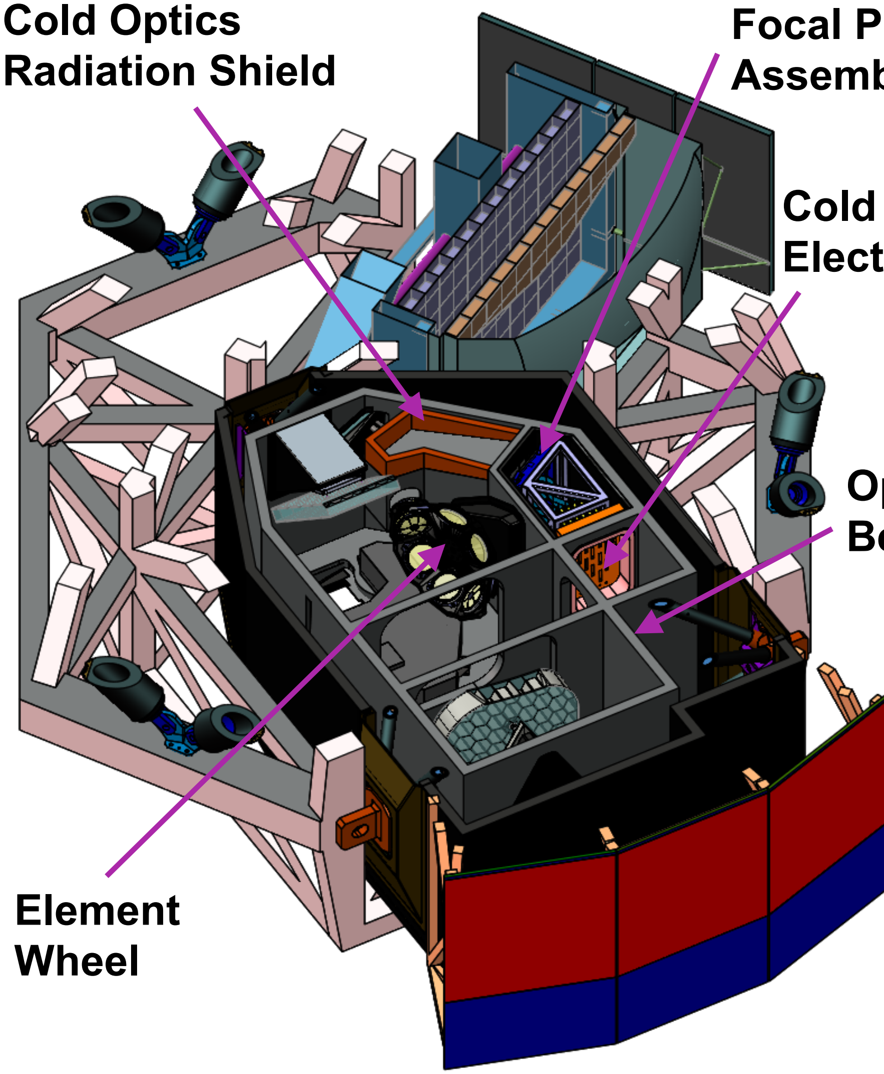
Payload Design to Minimize Telescope Risk

- Exelis/JPL/Study Office have worked closely to understand the structural capability of the telescope aft metering structure.
- Current design with the instrument carrier as the interface between the spacecraft and the payload provides substantial margin at the qualified telescope interfaces.
  - Instrument carrier is the prime optical bench for the payload, telescope and both instruments are attached to it.
- Telescope operating temperature baseline is 282 K and is within the qualification limits of the heritage program.
- Electronics and actuators that are not available will use the latest designs from the Exelis product lines.

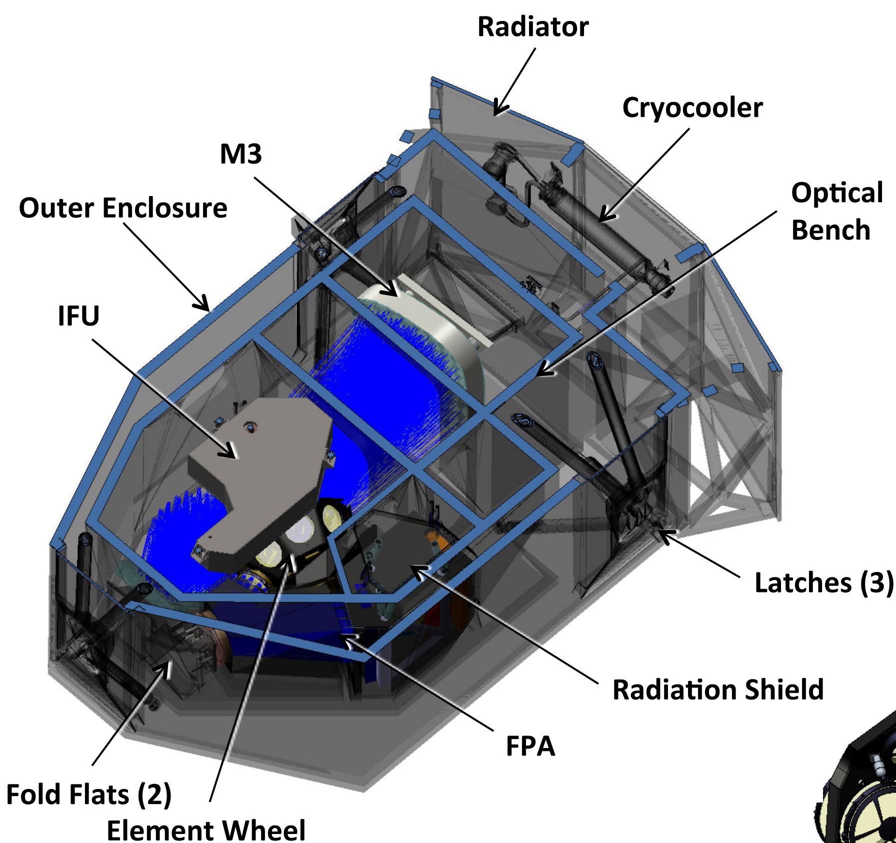
Wide Field Instrument Overview

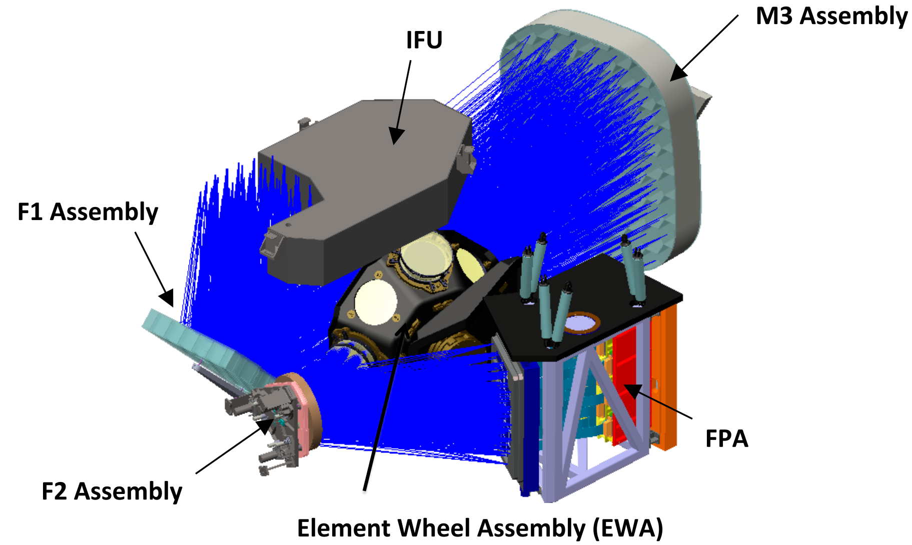
Key Features

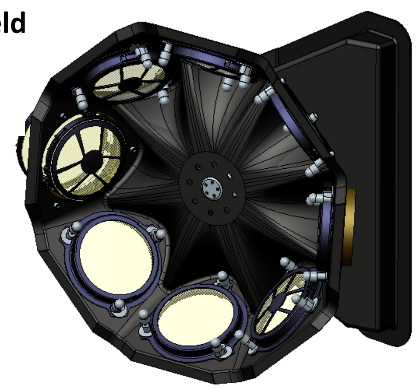
- Wide field channel instrument for both imaging and spectroscopy
  – 3 mirrors, 1 powered
  – 18 4k x 4k HgCdTe detectors cover 0.76 - 2.0 μm
  – 0.11 arc-sec plate scale
  – Single element wheel for filters and grism
  – Grism used for GRS survey covers 1.35 – 1.89 μm with R = 461λ (~620 – 870)
- IFU channel for SNe spectra, single HgCdTe detector covers 0.6 – 2.0 μm with R between 80-120

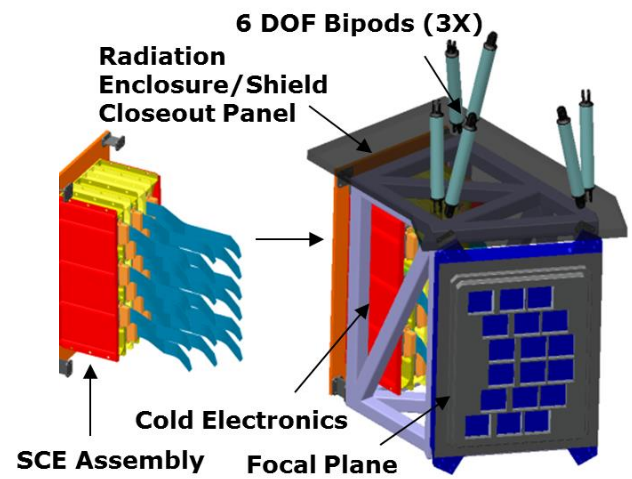


Wide Field Instrument Layout and Major Subassemblies







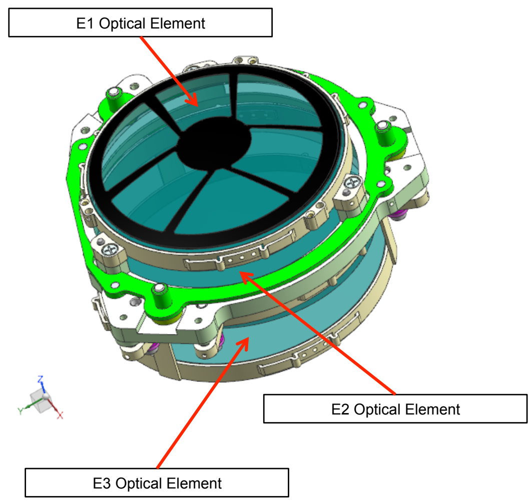


Wide Field Detector Technology Maturation Progress

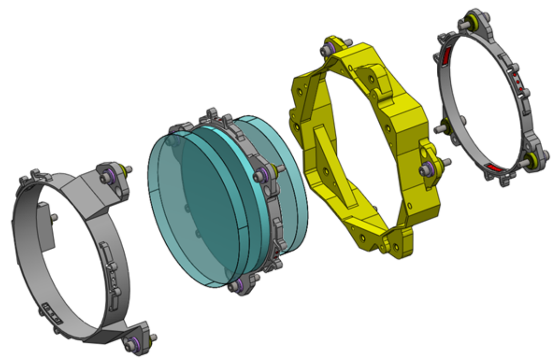
- Detector Technology Development Plan released with 5 key milestones identified to mature the HgCdTe detectors by the end of CY16.
  - First two milestones successfully completed.
- The Teledyne/GSFC Detector Team has completed a series of experiments (banded arrays) to determine the optimum detector composition for WFIRST. Full array flight composition detectors deliver this summer and will be characterized in the GSFC Detector Characterization Lab.
- The detector Read Out Integrated Circuit (ROIC) design has been optimized for WFIRST performance.
- Developed test hardware to eliminate hybridizing marginal ROICs to good detectors.
- Infrastructure – numerous investments have been made in the GSFC Detector Characterization Lab (DCL) to characterize/ qualify individual detectors and test the entire focal plane

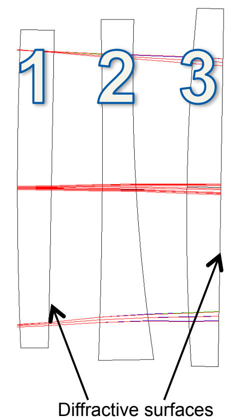
Other Wide Field Risk Reduction Activities

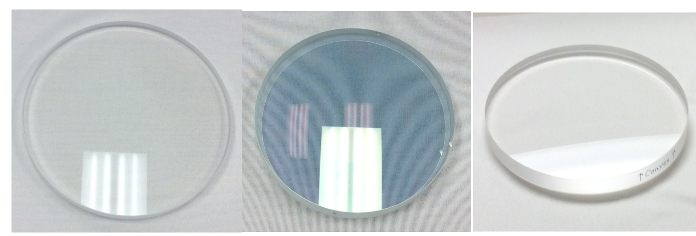
- The Wide Field element wheel presents unique challenges due to the large optical FOV of the instrument and the tight space that is available inside the instrument for the element wheel.
- The performance and manufacturability of the element wheel design are being examined in this engineering development hardware.
- The Wide Field grism presents some challenges due to its wide field of view, large dispersion, broad spectral range, relatively small F/#, and the high efficiency diffractive surfaces.



Grism mechanical design

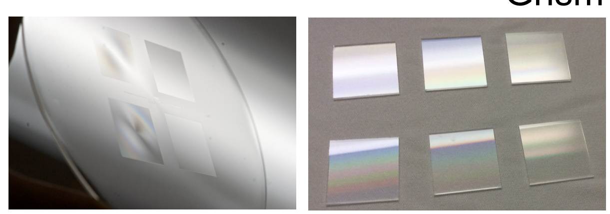






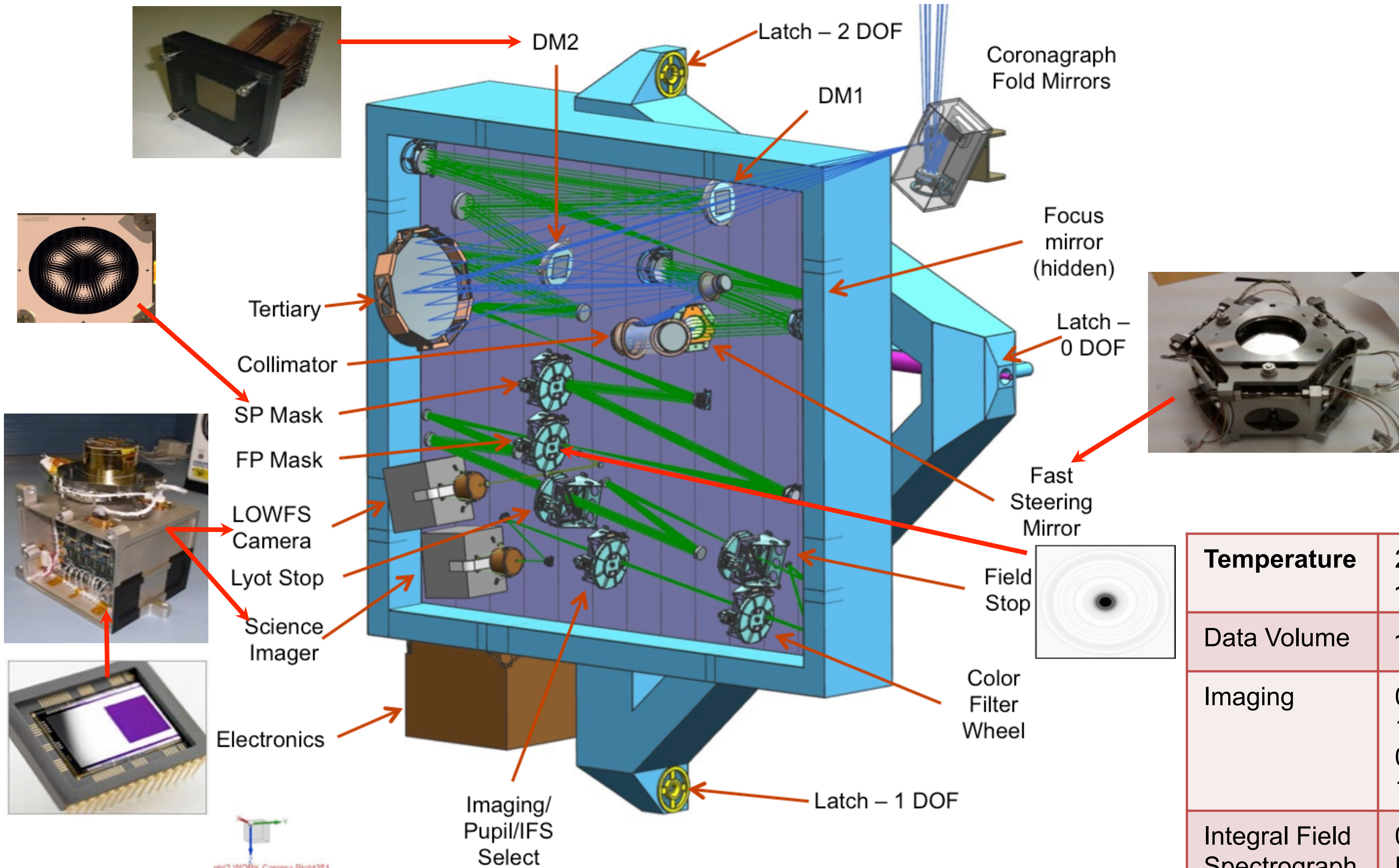
Grism procured substrates

Grism mount



Grism grating samples

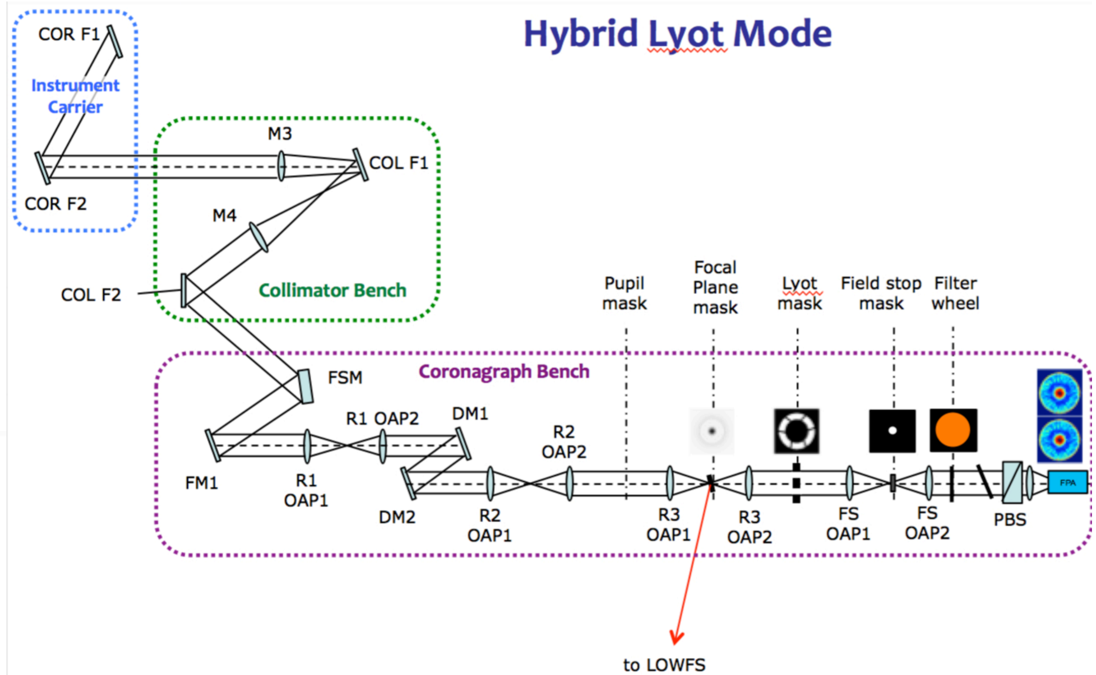
Coronagraph Instrument Overview

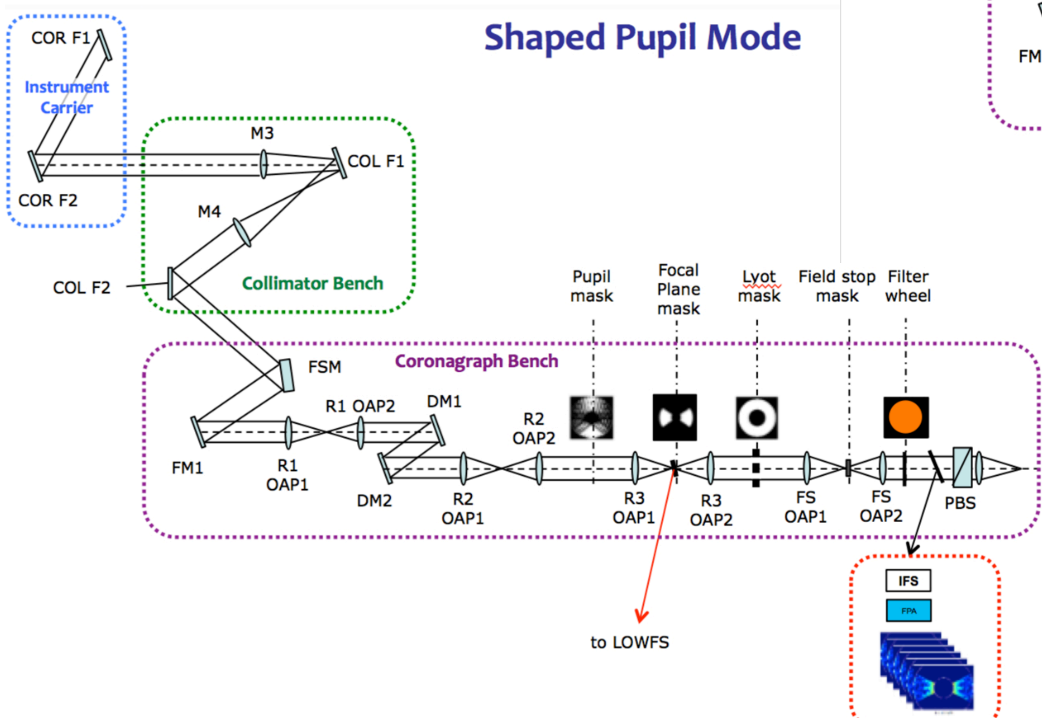


Temperature	293 K for instrument ~165 K for cameras
Data Volume	~30 Gbits/day
Imaging	0.43 – 0.97 microns, 1.63" FoV (radius), 0.01" pixel scale, 1K×1K EMCCD
Integral Field Spectrograph	0.60 – 0.97 microns R~70

Primary Architecture: Occulting Mask Coronagraph = Shaped Pupil + Hybrid Lyot

- SP and HL masks share very similar optical layouts
- Small increase in overall complexity compared with single mask implementation



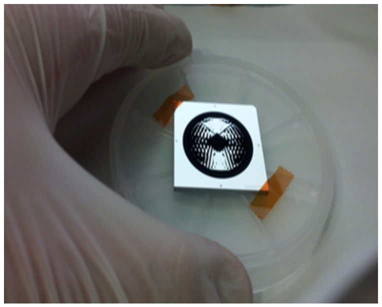


- In "SP mode" provides the simplest design, lowest risk, easiest technology maturation, most benign set of requirements on the spacecraft and "use-as-is" telescope. This translates to low cost/schedule risk which is critical for the independent CATE process.
- In "HL mode", affords the potential for greater science, taking advantage of good thermal stability in GEO and low telescope jitter for more planet detections in a shorter time

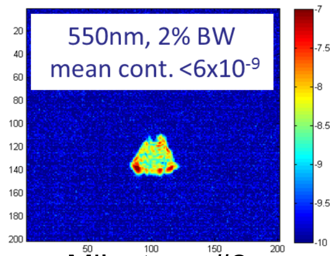
Coronagraph Technology Development Highlights

Reflective shaped pupil mask

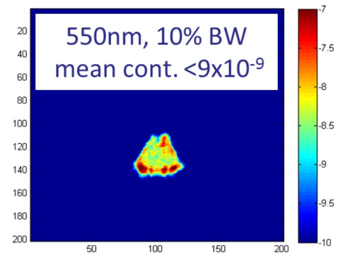
- Black Si on Al mirror coating demonstrated at JPL/MDL and Caltech/KNI
- High contrast demonstrated at HCIT



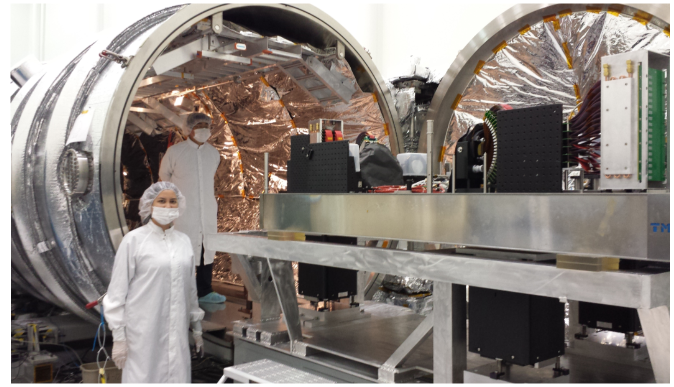
Milestone #1



Milestone #2

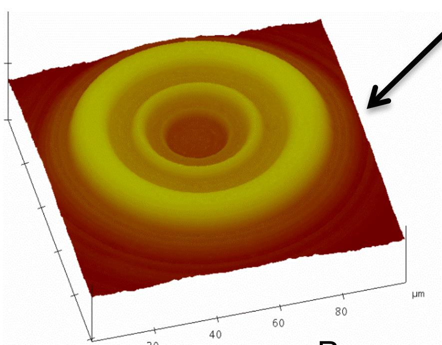


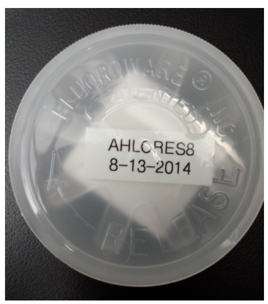
Preview of Milestone #5

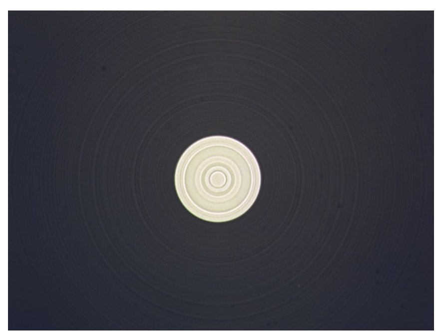


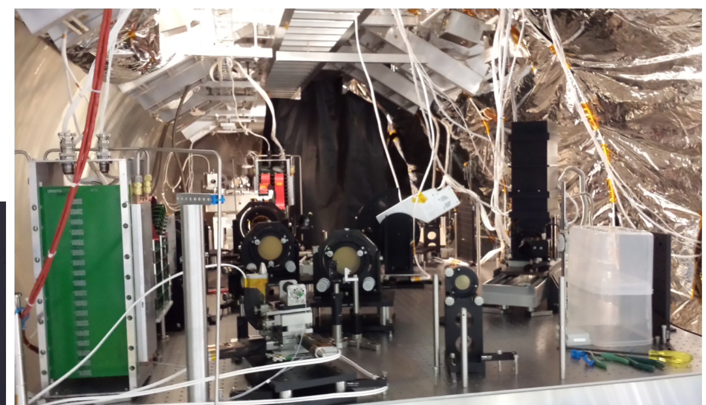
Transmissive hybrid Lyot mask

- Circular mask fabricated and measured
- Testbed commissioned on 8/15/2014









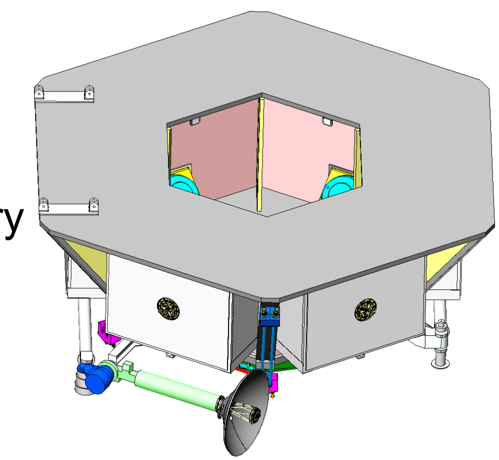
Progress for Milestone #4 to be completed this month

Coronagraph Technology Maturation Progress

- High contrast testbed results have demonstrated that better than 10^{-8} raw contrast is achievable with the WFIRST 2.4-m telescope.
- On track to demonstrate dynamic, broadband high contrast testbed performance during formulation.
- Significant investments in deformable mirrors, detectors, low order wavefront control, mechanisms and post-processing algorithms essential for high contrast coronagraphy.
- Developing an Integral Field Spectrograph (IFS) testbed at GSFC for delivery to JPL high contrast testbed this year.

Spacecraft Overview

- Design relies on recent GSFC in-house spacecraft electronics designs
- Spacecraft module design enables serviceability and leverages designs from the Multimission Modular Spacecraft (MMS).
- Uses a distributed avionics architecture to facilitate modular approach
- Structures/Mechanisms
  - Spacecraft bus structure is aluminum honeycomb with composite facesheets, instrument carrier is a composite truss structure, qualified as an assembly
  - Each High Gain Antenna (HGA) contains 2-axis gimbal
- Thermal
  - Passive cooling with coatings, MLI, and heater control
- Power (SDO & GPM heritage)
  - Internally redundant PSE, supplies power, controls array, battery
  - Fixed, body mounted arrays, ~2400 W average power
  - Li-ion batteries for peak eclipse of 72 minutes
- C&DH (SDO & GPM heritage)
  - Platform for FSW: gathers TLM, sends commands, FDC
  - Low rate bus for housekeeping and spacecraft control
  - High speed science data interface between instruments and Ka downlink
    - End-to-end high speed test bed demonstration by end of 2015.



Spacecraft Overview

- Comm
  - Continuous downlink to dedicated ground station, same concept as SDO
  - S-band omni antennas for uplink and housekeeping data downlink
  - Ka-band for science data is 600 Mbps
    - GSFC developed transmitter (update of SDO design) with a capability of 1.2 Gbps (prototype on schedule for completion in early 2015)
- Attitude Control/Prop
  - 3-axis stabilized using 4 reaction wheels with thruster unloading
  - 14 mas drift & 14 mas jitter, RMS/axis
  - FGS uses guide window data from wide field focal plane
  - Mono-prop system for station-keeping, momentum unloading and end of life disposal

Observatory Integrated Modeling

- Recent focus of Observatory analysis has been on integrated modeling (STOP and Jitter).
- Model fidelity is extremely high
  - Benefit of using the existing telescope
  - Required to optimize coronagraph mask designs
  - Critical for assessing PSF ellipticity for WL
- WFI STOP stability specs met with margin (10x) even for an extreme WFI Worst Slew Case w/MUFs applied
  - WFI spectroscopy and IFU modes and CGI STOP stability analysis in progress
- WFI Jitter stability specs met with margin (1.3x) for all disturbance sources even with MUFs applied
  - Modeled 4 RWAs, cryocooler and HGA jitter disturbances
  - WFI spectroscopy and IFU modes and CGI Jitter stability analysis in progress

Preliminary Coronagraph STOP Results

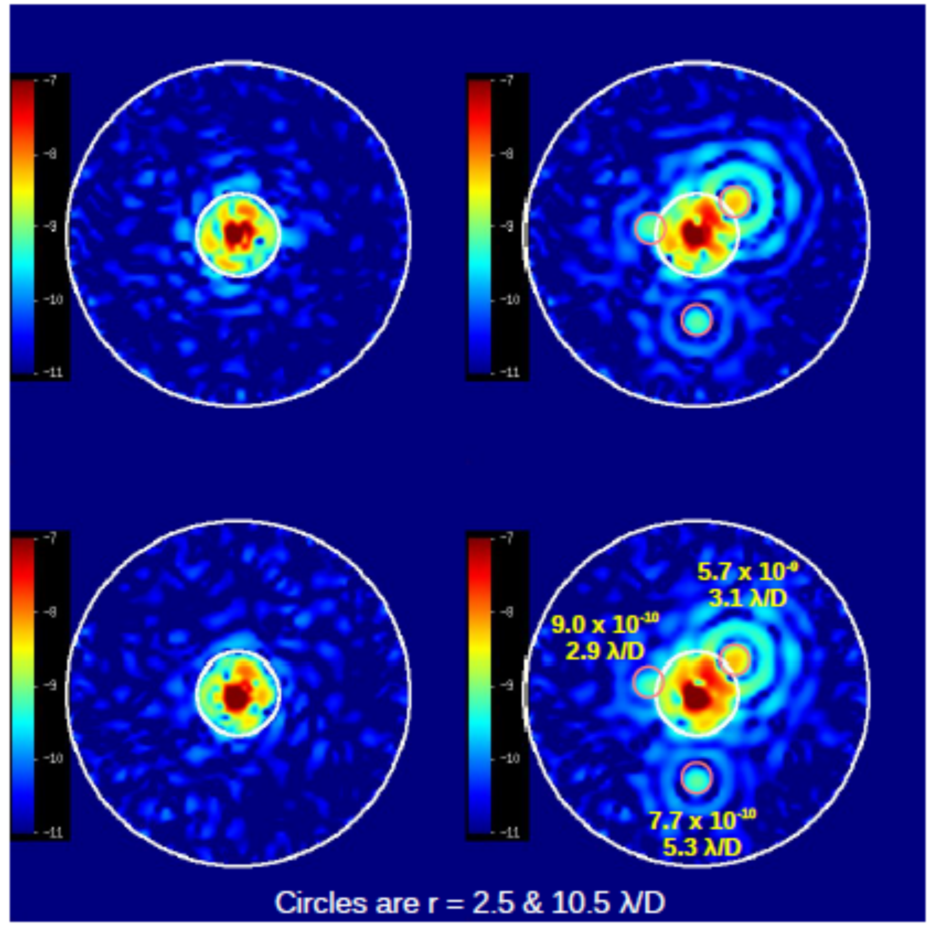
"Hot Off the Presses"

No planets | With planets (circled)

|47 Uma - β Uma|

Initial simulations of coronagraph performance in WFIRST-AFTA environment indicate that the coronagraph is likely to achieve all performance goals with the current, unmodified telescope.

|47 Uma - 61 Uma|



Color differences between these stars are not important in 10% bandpass.

Absolute differences of the mean images with DM LOWFC
(1000 sec LOWFS integrations)

Path Forward

- Optimization of the Reference Design
  - Study L2 mission concept and perform science/cost trade vs. GEO configuration
  - Study non-exoplanet uses for the coronagraph
  - Perform analysis to improve microlensing event rate predictions
  - Refine wide field IFU design to optimize wavelength range and resolution, and slice scale and sampling of the slices
- Systematic Error Control
  - Develop a calibration strategy
  - Characterize astrometric performance of the WFI
- Synergies with Other Observatories
  - Survey the need for precursor observations for microlensing, low z SNe and RV studies of coronagraph targets
  - Study opportunities for joint observations and requirements for joint analyses with Euclid, LSST and other ground telescopes
- Coronagraph
  - Develop more detailed coronagraph DRM
  - Perform deeper investigation of effects of coronagraph polarization and PSF subtraction
  - Assist with development of wavefront control technology
- Policy Issues
  - Consider possibilities for foreign involvement
- Observatory
  - Further refine servicing architecture and ops concept

Summary

- Recent infusion of additional funding has allowed significant progress in technology maturation as well as additional fidelity in the design reference mission.
- WFIRST-AFTA with the 2.4-m telescope and coronagraph provides exciting science program, superior to that recommended by NWNH and also advances exoplanet imaging technology (the highest ranked medium-class NWNH recommendation).
- Great opportunity for astronomy and astrophysics discoveries. Broad community support for WFIRST.
- Key development areas are anchored in a decade of investments in JPL's HCIT and GSFC's DCL.
- Opportunity to enhance the scientific return from JWST and WFIRST if missions overlap